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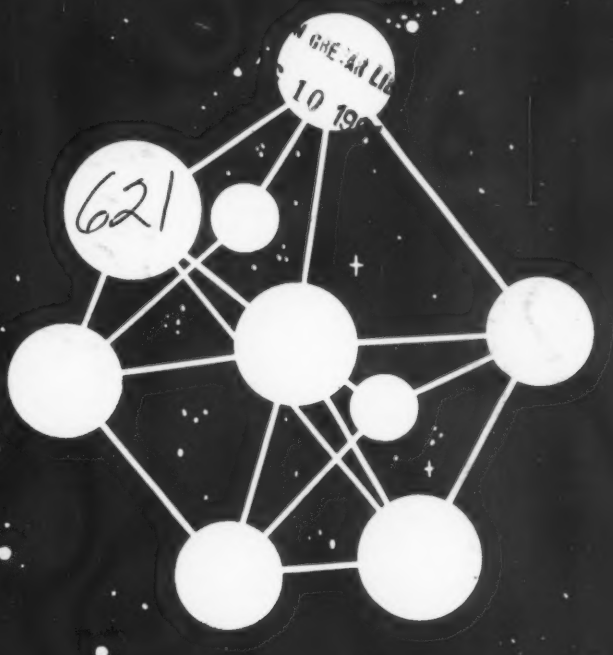

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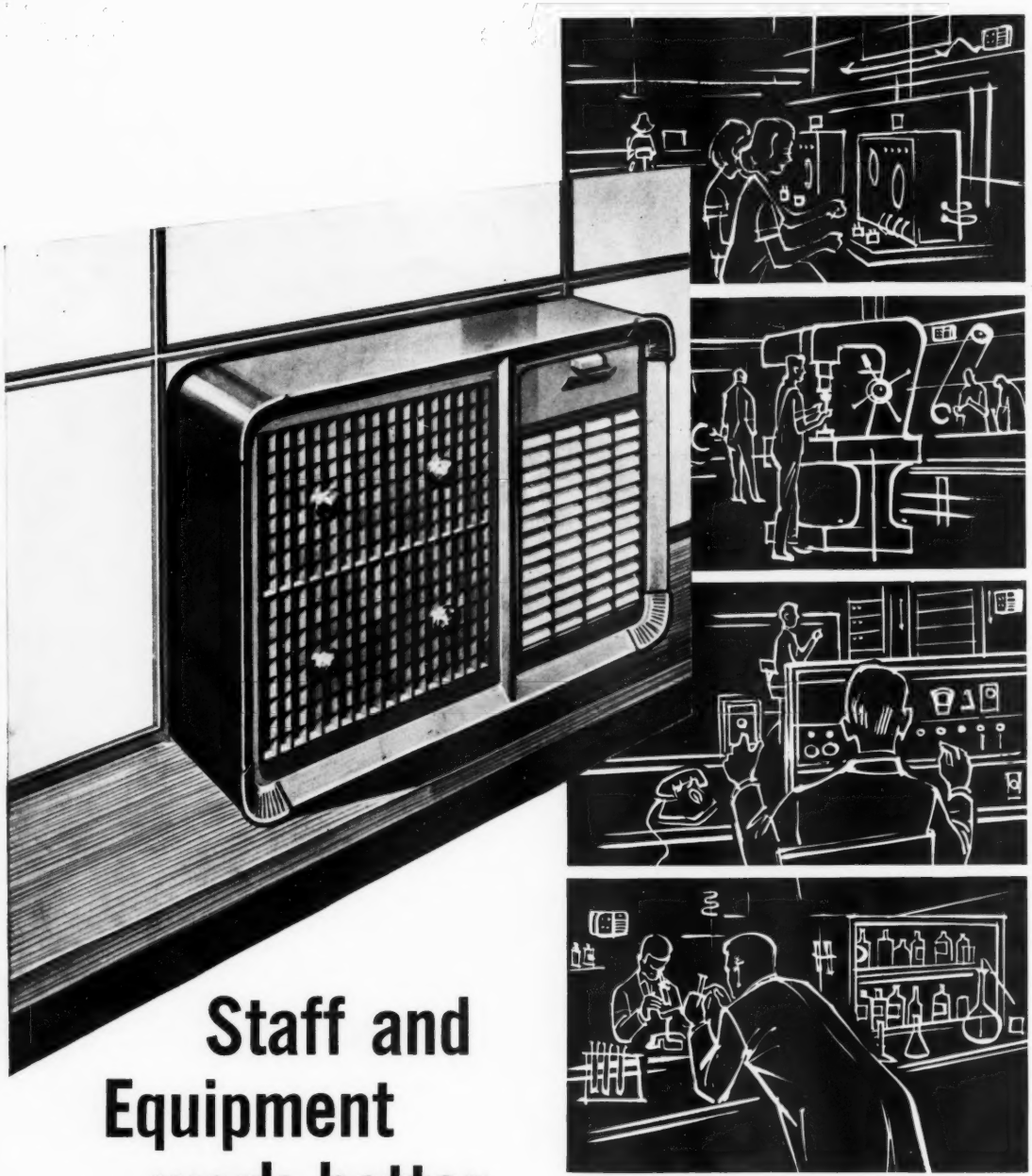

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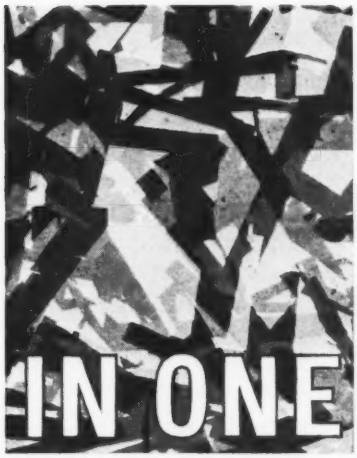

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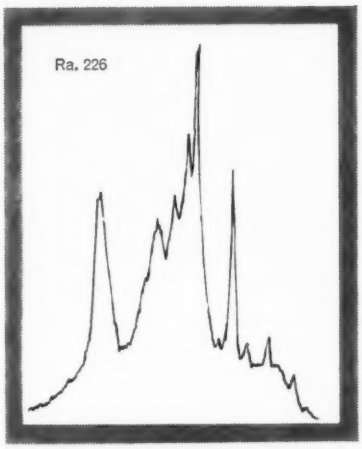

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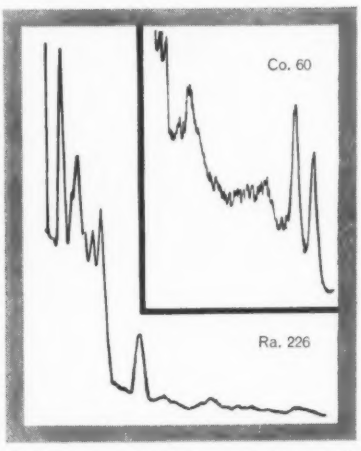

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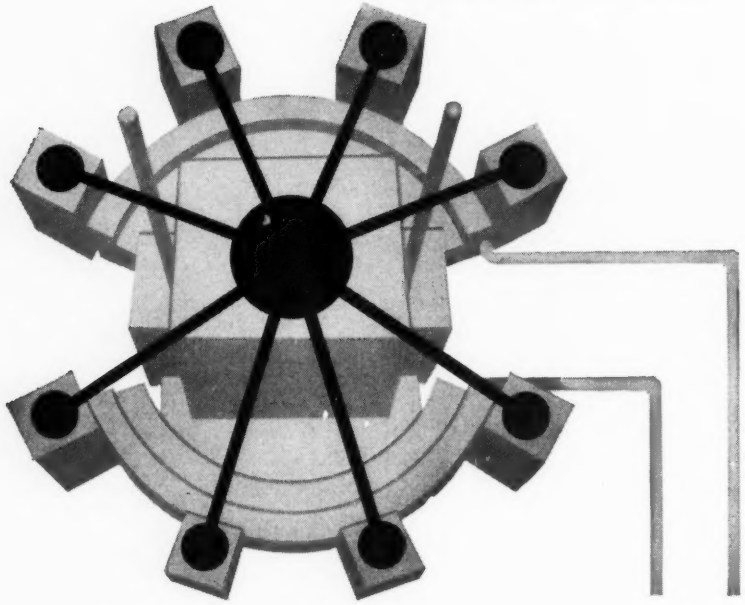
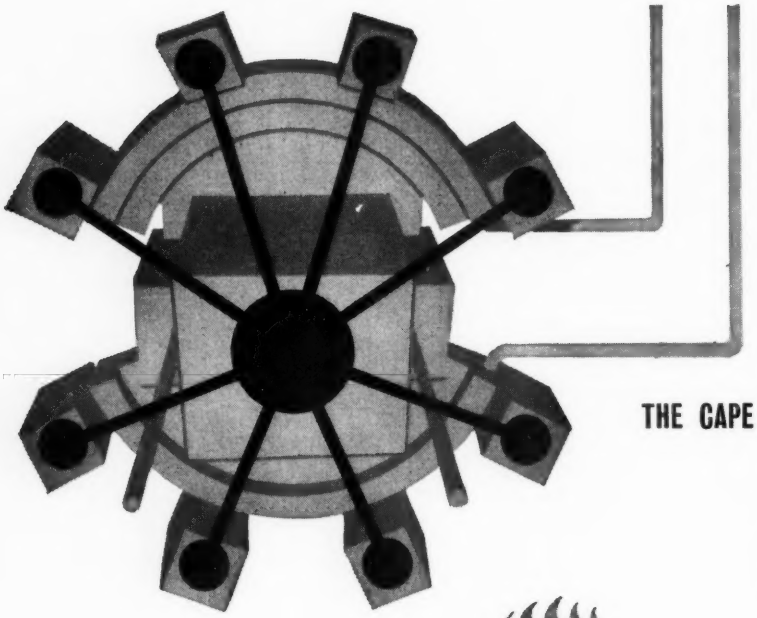


BERKELEY—a challenge to insulation



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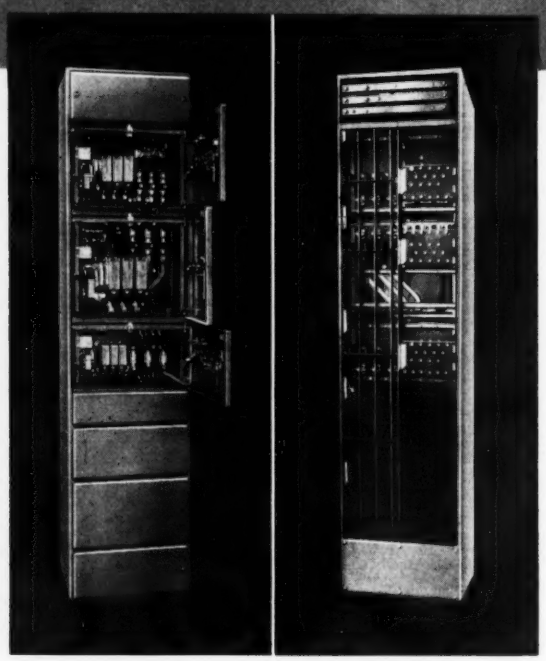

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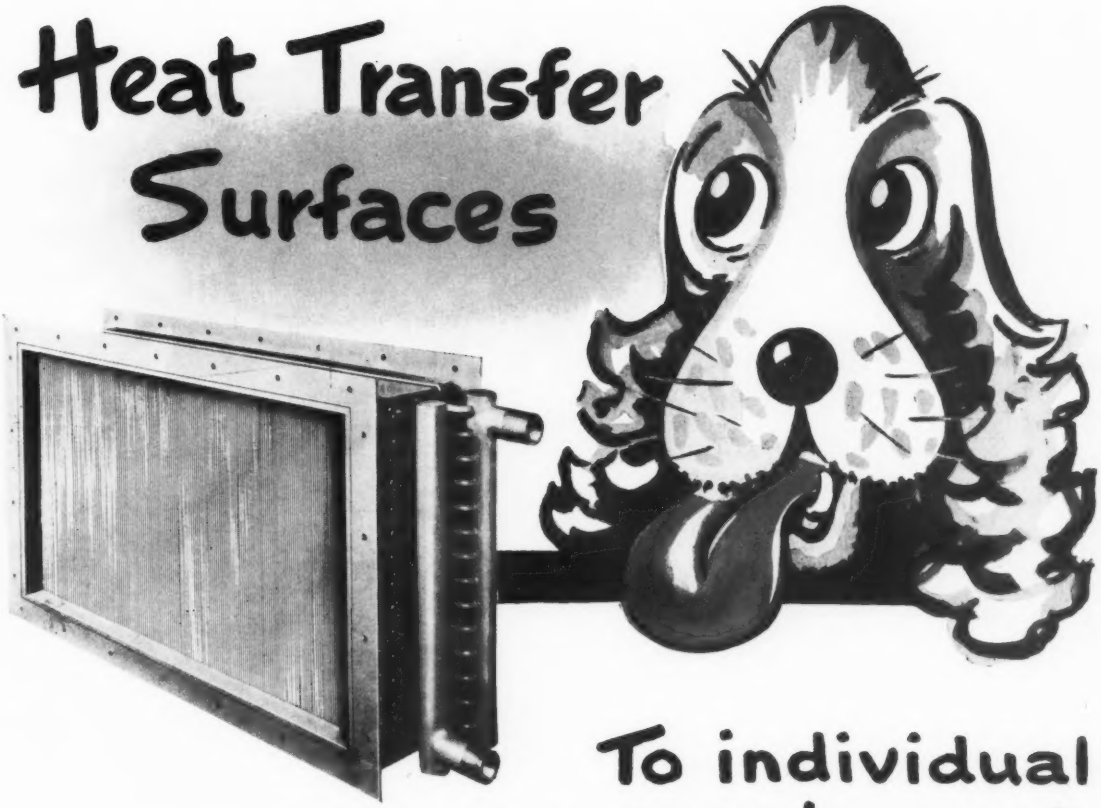

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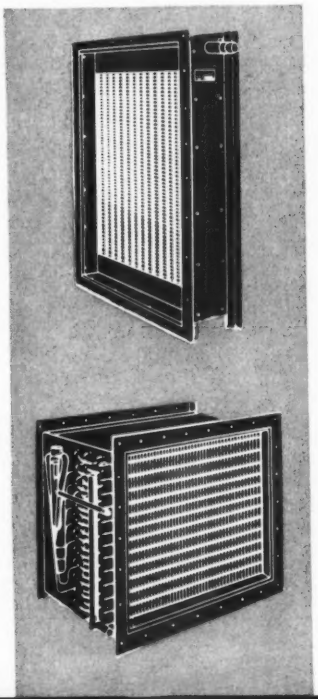

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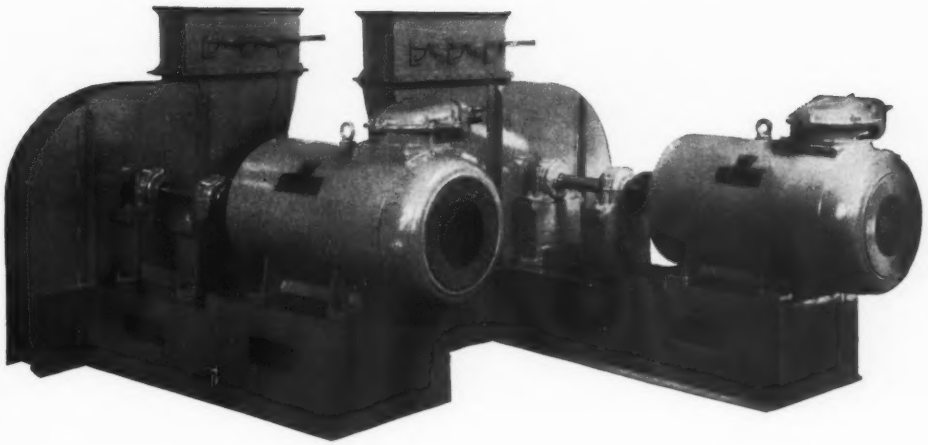

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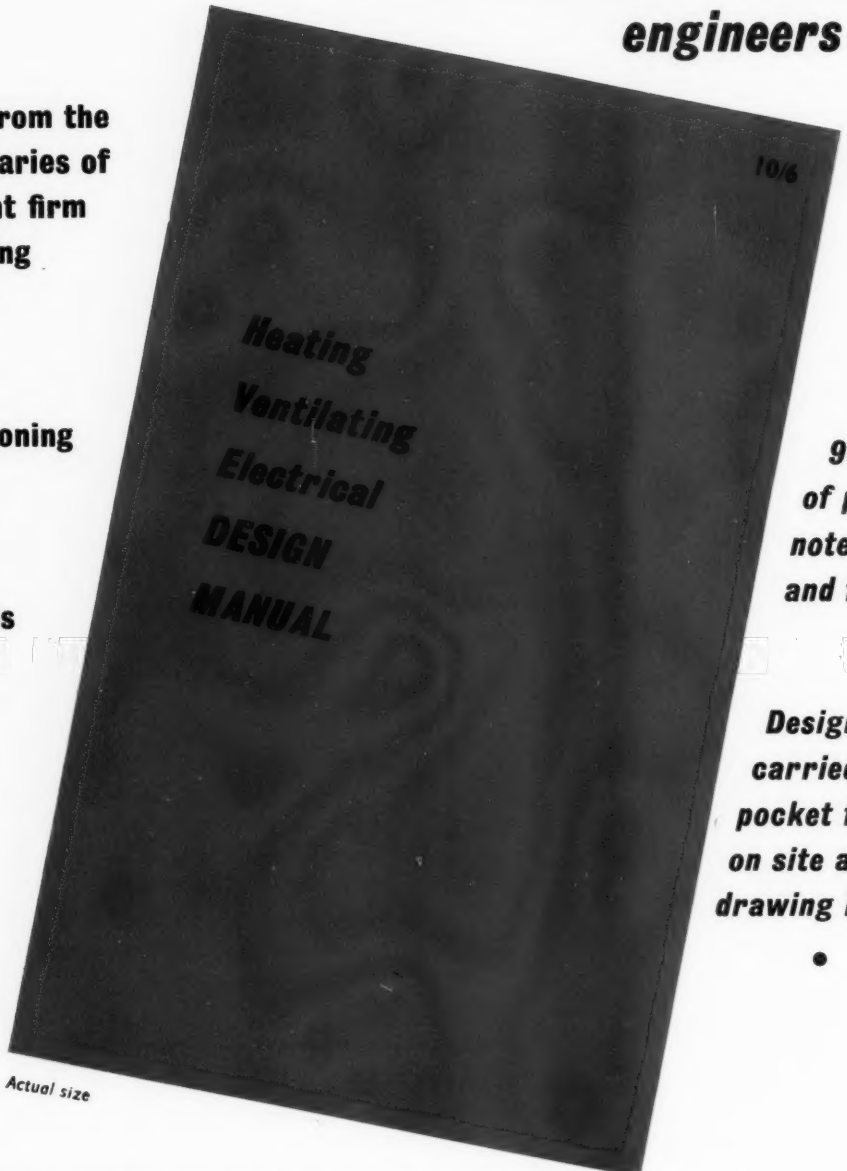

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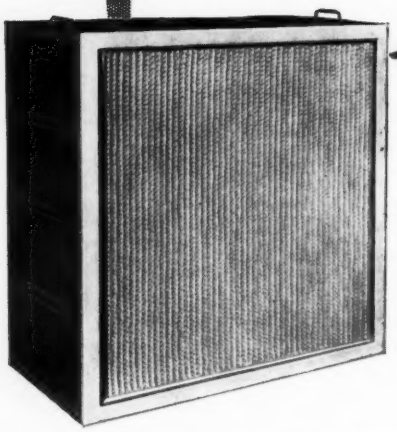

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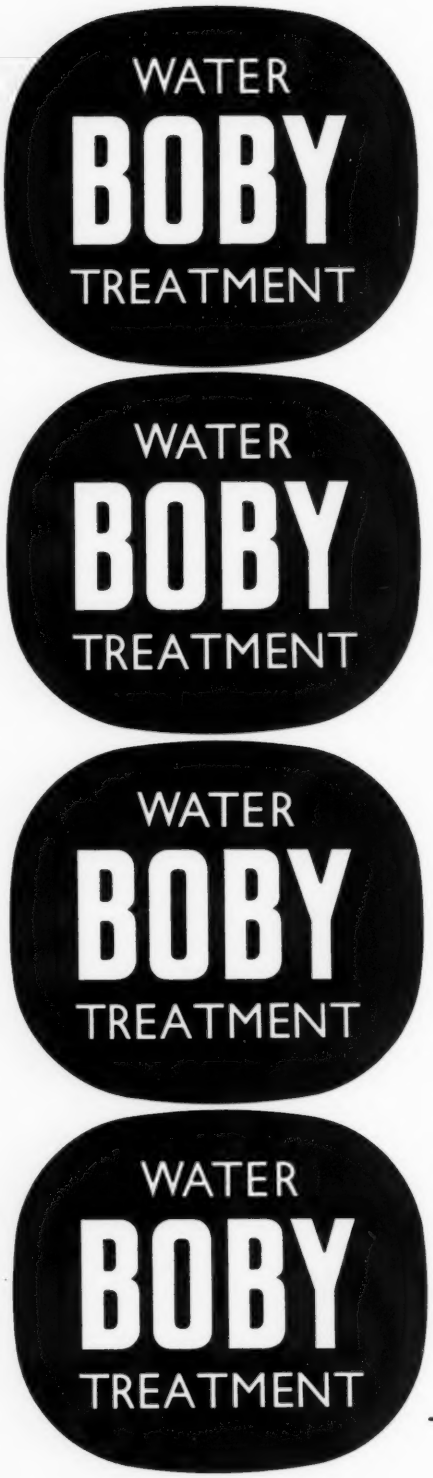

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Classroom and Laboratory

Arising out of a proposal by Dr. F. R. Paulsen, at a Council Meeting of the Institution of Nuclear Engineers, several hundred teachers of nuclear science were asked to report on simple apparatus and methods used or those which might be useful for practical demonstrations in instructional courses. The response was enthusiastic. From all parts of the world, from teachers in Universities, High Schools and Colleges, from research workers, manufacturers and public relations experts, have come many ideas. As a service to teachers, and also to other workers in nuclear fields, we are now publishing the many suggestions put forward. Each suggestion carries the identity of the person who put it forward, and also a reference number. The latter will facilitate enquiries sent in by readers requiring further information. Readers are invited to submit suggestions for inclusion in this feature

No. 69 Thickness Measurement

United States Atomic Energy Commission.

A GM counter assembly is switched on and allowed to warm up. The voltage is adjusted to the working potential of the GM tube. A source of beta radiations suitable for this experiment is a plaque of RaD and RaE, as made by the National Bureau of Standards, with a count rate of 10^6 d.p.m. Between this source and the GM tube, which are 4·5 cm apart, is interposed an eight-layer thickness of elastic rubber dam (latex dental dam, medium) or a piece of inner tubing or other heavy rubber. The meter reading is recorded. Now the rubber is stretched to about twice its original length, and the reading again recorded. The count rate is reduced as the rubber thickness increases, and *vice versa*. This is the principle of industrial beta gauges for thickness control and measurements.

No. 70 Isotopes of the same element

United States Atomic Energy Commission.

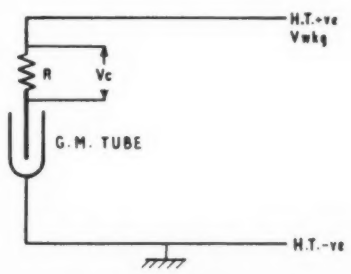
The object of this experiment is to demonstrate that isotopes of the same element are chemically identical.

Into each of two small flasks are placed 25 ml samples of 2N KI solution, and to one of these is then added about 4 microcurie of I131 in the form of KI. Both samples are treated with excess of lead nitrate solution until precipitation of lead oxide is complete. Each precipitate is filtered and washed, and then tested with the GM counter. The tagged iodide gives rise to a lead iodide precipitate which is radioactive, while the other one is not. Both filtrates are found to be non-radioactive. Now both precipitates are treated with 5 ml of saturated sodium carbonate solution. The white precipitates of lead carbonate left are found to be inactive, while the filtrate from the tagged iodide precipitate is found to be radioactive. Lead iodide prepared from inactive and from active iodide solutions is found to be identical in appearance and also behaves in the same way when treated with sodium carbonate.

No. 71A. GM Tube Probe

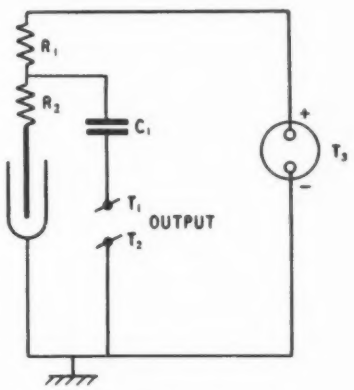
Mullard Educational Service, U.K.

The illustration below shows the basic counting circuit in which the tube is connected across the H.T. supply via the resistor R. Any fluctuations in tube current due to ionization in the gas cause additional p.d. across the resistor R, and this results in a counting voltage V_c which can trigger more complex equipment to produce a click in a suitable headphone. Fig. 71*b* shows the practical set-up based on this circuit. The resistor R is now replaced by two, R_1 and R_2, so that the counting voltage may be taken between the junctions of the two resistors and the h.t. negative line (earth). This increases the safety factor and may give a large counting voltage. The capacitor C_1 is a d.c. block, which ensures that the output voltage is due only to ionization. The resistors



71a—The basic counting circuit

R_1, R_2 are each 2·7 Mohm, ¼w. The GM tube may be a Mullard MX108, MX115 or MX142, these are interchangeable. All three have a 2-pin base, 370v threshold, 100v plateau. The MX108 is a beta end-window type, with unshielded background of 45 c.p.m. the MX142 is a liquid sample tube, and the MX115 is



71b—GM probe circuit

a gamma tube with unshielded background of 45 c.p.m. All three operate at 425v, the counting pulse being 12v. The working voltage is easily obtained from standard power packs. The probe contains the GM tube, resistors and a pair of terminals for the headphone. Power supplies are brought in via a twin core cable and a two-pin plug and socket T_3, giving maximum portability. The main part of the probe is made from an adaptable conduit box with a large hole bored at one end to take the 2-pin base for the tube. Resistors, capacitor and cable end are inside the box. Output terminals are fixed to the unit, which also has a carrying handle on top. The capacitor C_1 is a 300 pF, 100v wKg, the tube base is a special two-pin Belling and Lee L773, the terminals T_1 and T_2 are of standard screw-down type, while T_3 is a 2-pin plug and socket.

Shell demonstration

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Thoughtful production executives who want to know more have only to write for the book, *'Selecting Your Cutting Oils', to Lubricants Dept., Shell-Mex House, London, W.C.2.*

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No. 72 Gamma Measurements with an Ionization Chamber

The electroscope possesses sensitivity making it ideal for comparing radioactive sources and in this experiment it is applied to the gamma rays from Co60.

Background drift is established so that corrections for this may be applied. For this purpose the electroscope is well shielded from all radioactive sources, charged, and allowed to drift for 20 min or better, for two periods of 10 min, so that an average drift rate may be determined, in terms of scale divisions per minute. This rate should be less than 0·5 divisions/min.

The reticular scale of the electroscope is now tested for linearity by comparing the times required to discharge from reading 10 to reading 20, 20 to 30, 30 to 40 and so on. These times should, of course, all be equal. A radioactive source is used here to make the discharge rate easily measurable, its distance being adjusted to give a discharge time of 2-3 min for 10 divisions.

The dose rate due to radiation at a point at a given distance away from a radioisotope is represented by the empirical formula $R = I\gamma C(d_1/d)^2$ where R is the dose rate in mr/hr, $I\gamma$ is the constant for a particular isotope, in mr/hr/mc at 1 cm, and C is the number of millicuries (mc) of the isotope being studied. The d and d_1 values are respectively the distance from the isotope in cm and 1 cm. The sensitivity of the instrument may be determined by the equation $N = kr$, where N is the discharge rate in scale divisions/sec, k is the sensitivity in divisions/per sec mr/hr, and R is the dose rate as determined by the first equation given above. The sensitivity k is determined for various distances by observing N and calculating R from the first equation. A Co60 standard may be used. For this, the C value must be known. The I value is calculated from the following equations, all of which are only good approximations:

$$\text{mr/hr/mc} = \frac{1{\cdot}59 \times \text{mc of Co60}}{(\text{distance in yd})^2}$$

$$\text{mr/hr/mc} = \frac{14{\cdot}4 \times \text{mc of Co60}}{(\text{distance in ft})^2}$$

$$\text{mr/hr/mc at 1cm} = \frac{14{\cdot}4 \times \text{mc of Co60}}{(0{\cdot}032)^2}$$

The electroscope is placed 50 cm from the standard Co60 preparation and the discharge rate N in div./sec for the sample minus the background drift, is calculated over the same part of the scale, for distances from the source varying from 50 to 250 cm.

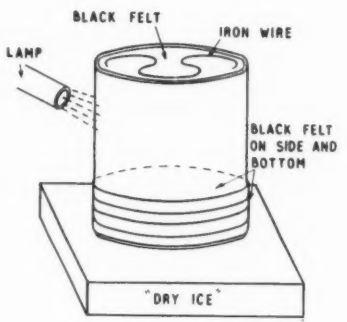
In these determinations the discharge is observed for either 10 scale divisions or for three minutes, whichever takes the longer. The N and k values are calculated for each distance, any corrections for non-linearity being applied as necessary.

No. 73 Continuous Cloud Chamber

United States Atomic Energy Commission.

The cloud chamber is made from a screw-capped jar, about 3 in. × 3 in. A disc of black felt is cut to fit snugly into the cap and another piece is cut to fit the bottom inside of the jar. This disc is held in place by means of a retaining ring made from about 15 in. of iron wire. The elasticity of the wire holds the felt in place even when the jar is inverted. Enough methyl alchohol is poured into the jar to just saturate both pieces of felt and then a slight excess is added. The cap is tightened on the jar, which is then inverted and placed on a block of dry ice.

Precipitation of droplets is seen almost at once when a very bright source of illumination is played into the jar. Now a gamma radiation source is placed close to the jar. This causes an increase in the size of the drops. After about ¼ hr, when conditions are stabilized, cloud tracks may be seen against the dark background, appearing at uneven intervals and best seen from an angle not too wide from the direction of the light beam.



No. 73

(*Left*) **Cloud Chamber made from a screw-capped jar**

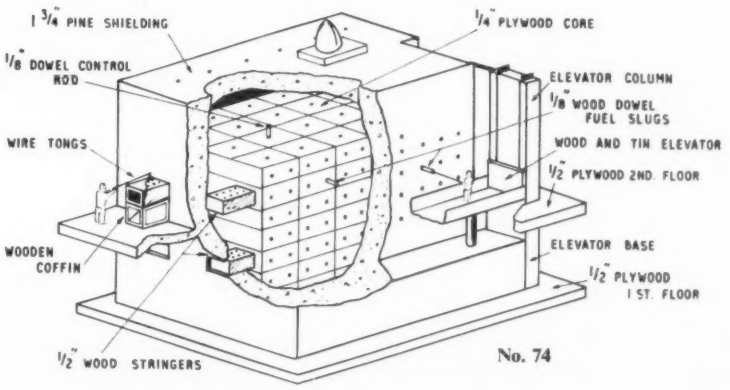
No. 74 A Model of a Uranium-Graphite Nuclear Reactor

Oak Ridge Institute of Nuclear Studies, U.S.A.

The model of a graphite pile consists of three major parts—the shielding, the floors and the core.

The shielding is made from three pieces of 1¾ in. thick white pine and two pieces of ¼ in. plywood. These pieces are to be assembled so that the 1¾ in. pine comprises the bottom and the two adjacent sides of an

(*Below*) **The uranium-graphite reactor model**



No. 74

open-top box, with the $\frac{1}{4}$ in. plywood forming the remaining two sides. Outside dimensions of the box should be $9\frac{1}{2}$ in. by 12 in. by $13\frac{1}{2}$ in. high. The cutaway portion of the shielding should be cut before assembly to facilitate sawing. After assembly the two pieces representing the base and column of the elevator are added. The base piece should be $1\frac{3}{4}$ in. $\times$ 2 in. $\times$ 20 in. and the column $\frac{3}{4}$ in. $\times$ 2 in. $\times$ 11 in.

The first floor is a piece of 2 in. plywood 16 in. wide and 20 in. long and the second floor may be of $\frac{1}{2}$ in. plywood pieces (three) 4 in. wide, fastened on three sides of the shielding and cut to match the cutaway in the shielding (see Fig 74).

The core is a simple six-sided box approximately $6\frac{1}{2}$ in. $\times$ 9 in. $\times$ 11 in. high and is scored on two adjacent sides and top with a saw or other suitable tool, both horizontally and vertically, approximately $1\frac{1}{4}$ in. on centres. Holes, $\frac{1}{8}$ in. diameter, are drilled for the control rods and fuel slugs and short lengths of $\frac{1}{8}$ in. dowel rod are glued in a few holes to represent the control rods and fuel slugs.

At this stage it is advisable to paint the finished parts and set them aside to dry while work proceeds on the " coffin," elevator and small parts. The shielding is painted concrete colour and while the paint is still tacky, it is sprinkled with sand or fine grit up to the edges of the cutaway, to represent concrete. The core is painted flat black, to represent graphite blocks.

The elevator end and bottom are made from $\frac{1}{2}$ in. plywood or masonite, cardboard strips being glued to this to represent the sides of the elevator. The pulley brackets are made from thin metal scraps, such as cuttings from a " tin " can and the pulleys are made from washers or large dress snaps with thread to represent the cables. The coffin is made from small wooden blocks set on a $\frac{1}{8}$ in. dowel frame as a stand.

When painted parts are dry the core is secured in the floor centre, and the shielding is placed over it, with an air gap of about $\frac{1}{2}$ in., the scored lines of the core being allowed to show through the cutaway portion of the shielding.

Other small parts are painted to suit and these are then fixed to the model as shown. Small plastic figures from a toyshop can be added.

No. 75 Demonstration Cloud Chamber

Spindler and Hoyer KG, Germany.

Although the Wilson cloud chamber is not generally used to demonstrate nuclear particles to large masses of people a version of this instrument, designed by Hilsch and ideal for demonstrations to large audiences has been put on the market by Spindler and Hoyer, KG, of Göttingen, Germany.

This cloud chamber is placed between an arc lamp and a condenser on the one hand and a projection lens and screen on the other. The chamber has a rod for mounting in a bracket and consists of a metal cylinder 40 mm long and 170 mm in diameter, enclosed at both ends by glass end plates. Mounted between

The cloud chamber

the plates and coaxial with the cylinder is a metal screen held in position by locating pins. This screen is surrounded by damp felt, forming the cloud chamber proper, separating it from the annular outer space. A metal rod projects into the chamber through a hole drilled in one glass plate and on its end it bears a capsule carrying the radium preparation. A d.c. potential of about 200v is applied across the two terminals, one of which is connected to a metal ring embedded in the inner surface of one glass plate, while the other is connected to the cylindrical housing. The annular compartment of the cloud chamber is connected through its socket to a valveless piston pump placed on the floor by a large tube about $1\frac{1}{2}$ m length. By raising the piston through its short stroke, it is possible to cause the air in the chamber to expand. The radium preparation is sufficient to show about 10 tracks of alpha particles on the screen at each expansion.

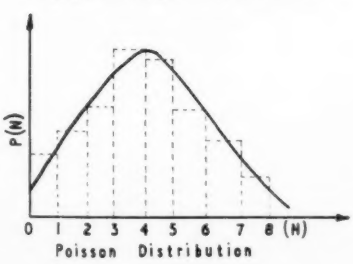
The approximate cost of this cloud chamber is as follows: cloud chamber Ref. No. 12 1430, £25; alpha preparation Ref. No. 12 1431, £4; air pump Ref. No. 12 1432, £7; tube, 1·5 m long Ref. No. 12 1433, £1.

No. 76 Distribution Experiment

Societe d'Applications Industrielles de la Physique, France.

A GM assembly is used for this experiment and all radioactive sources are kept remote from it. When the instrument has been switched on long enough to become thoroughly " warmed up," counts of background are taken at intervals of 5 or 10 sec, until 100 values are obtained. A histogram is now plotted, in which the count values (0, 1, 2, 3, 4. . .) etc. are plotted against the frequency with which these counts are recorded The mean value is calculated by dividing the sum of all the counts by 100. The standard derivation, $\bar{V}$, is equal to $(\bar{N}/100)^{\frac{1}{2}}$ where $\bar{N}$ is the sum of all the readings. Distribution is not quite symmetrical about the mean value, the latter being slightly larger than the most probable value. The number of counts in the given time interval will be expressed as $\bar{N} \pm \bar{V}$.

A graph showing Poisson distribution



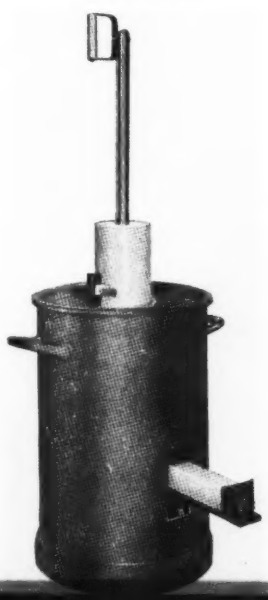
No. 77 Convenient Neutron Source

Spindler and Hoyer, K.G., Germany.

The German firm of Spindler and Hoyer, KG, of Göttingen, manufacture a very convenient neutron source which can be used for experiments in radioactivation. A mixture of beryllium powder and radium salt emits neutrons by the nuclear reaction $Be^{9}_{4}+He^{4}_{2}=C^{12}_{6}+n^{1}_{0}$ so that each milligramme or millicurie of radium produces about $1{\cdot}2\times10^{4}$ neutrons/sec, with energies up to 14 MeV. If the source is inside a cylinder of silver, indium or rhodium, surrounded by 18 cm of paraffin, the neutrons pass through the metal and become slowed down, part of these thermal neutrons diffusing back to the centre where they react with the metal to give an isotope to the metal. The latter then undergoes beta decay, with production of an element one position higher in the periodic classification.

A paraffin container holds the neutron source and lead shield which serves to absorb gamma rays from the source. The wall thickness of lead in each direction is at least 56 mm. The source is pushed into the paraffin, which contains the materials to be activated. The source is thus placed centrally in the metal cylinder or in a liquid which is to be activated and which is uniformly surrounded by paraffin. The metal cylinder or the beaker which has to be activated is in the area of highest neutron flux. It is simple to exchange the radium-beryllium source for one of higher activity. After separation of the components (the lead shield with the preparation and paraffin container) it is simpler to move the equipment to another place. The lead container with the source can, after an experiment, be removed from the laboratory and stored where gamma rays will not disturb other work. For research or demonstrations, there are radium-beryllium sources available with 3, 5 or 10 mg of radium in a cylindrical nickel vacuum-tight container in a sealed glass tube. The yield in all cases is about $1{\cdot}2\times10^{4}$ neutrons/sec/mg. Since these are relatively weak sources, it is necessary in order to get sufficient readings on a counter, to activate only materials with a fairly high cross-section for absorption of slow neutrons. These activated materials should also have a fairly short half-life. Suitable substances for this purpose are silver, indium, rhodium and for organic work ethyl iodide or bromide are used. Prices are as follows: Radium-beryllium source 3mc, 13 5013, complete with paraffin container, lead container, 36 cm diameter, height 1·2 m, approximately £185; 5mc source, 13 5015, 10mc source 13 5011, prices on application.

A neutron source



No. 78 Autoradiograph experiments with plant material

John H. Woodburn, Walter Johnson High School, Maryland, U.S.A.

The technique used for preparing autoradiographs of plants may be used in some interesting ways, of which the following are examples:

(*a*) A plant with variegated leaves, such as a Coleus, is placed in 30 ml of water containing 1 ml of one microcurie/ml P32. Individual leaves are removed after 1, 2, 3, 4 and 5 hr, and their autoradiographs are prepared. It is found that there has been no uptake of P32. After considerably longer periods, however, there is uptake, but there is no difference between green and white leaf tissue in this respect. The effects of light and temperature might also be studied as might the uptake of other isotopes.

(*b*) Six different species of plants are placed in 20 ml of water containing one ml of 1 microcurie/ml S35 of I131. Different plants show some differences in their tendency to absorb these isotopes. The S35 has a radiation which can penetrate only very thin plant tissue.

(*c*) Root systems of two plants are divided into two tubes placed side by side. Thus, for example, one half of the roots of a ragwort may be placed in a solution of P32, the other half in water. The same may be done with clover or other plant. The radioactive solutions contain 0·2 ml of 1 microcurie/ml P32. After 7 hr, the plants are removed and autoradiographed. It is clearly shown that the P32 travels up the half of the root system immersed in the radioactive solution, but also travels down to the other half of the system. It would also be possible to determine in what type of tissue this translocation takes place.

(*d*) A sprouting tuber of dahlia is left for about a week in 20 ml of water containing one ml of 1 microcurie/ml P32. Slices of dahlia tuber are wrapped in transparent film and then autoradiographed.

(*e*) Thin sponge discs are floated in water in Petri dishes and seeds can then be planted on the sponge. As tracer isotope, one ml of 1 microcurie/ml P32 can be used. If seeds are added at about 5-day intervals, they may all be removed after the oldest have formed seedlings. Autoradiographs of them are prepared with 10-20 hr exposures. These photographs will clearly show when and how much radioactive material was absorbed during germination and growth of the seedlings. Sometimes quite unexpected results emerge. Thus, in the case of tomato seedlings, it is seen that S35 is absorbed in a non-uniform manner, being concentrated in small pockets. The reason for this is not clear.

No. 79 A Photographic Experiment

John H. Woodburn.

The luminous dial from a wristwatch is cemented to a piece of cardboard and wrapped with transparent film of X-ray type. These are then wrapped in black opaque paper, held down by a heavy weight or a few books and finally development of the film reveals the pattern of the luminous figures in the dial. Varying the exposure time from $\frac{1}{2}$ to 4 hours may give interesting results. In general, the film is left in the developer for 5 min, in the fixing solution for 10 min and finally in the washing liquid for 30 min.

Environmental Dispersion of Radioactive Waste

by J. C. Collins, BSc, MSE, AMICE, MRSH*

THE major public health problem associated with the development of nuclear energy and the processing and use of radioactive materials is the disposal of the inevitable waste products which arise. Every industry, at its inception, creates a new waste disposal problem and, since no two industries produce the same type of waste, individual solutions have to be found in each case.

In the past, these solutions have been devised all too often under the pressure of existing gross pollution. However, once an industry has become established and has already made some indiscreet discharges of waste, it is then much more difficult to institute effective control than it would have been in the early stages. The nature of radioactive waste makes it essential that this particular problem should be clearly understood before the expansion of nuclear techniques requires the discharge of such quantities of radioactive effluent as might cause environmental radioactive pollution.

In the early days of our industrial development a fully responsible and informed attitude towards waste disposal would have instituted a traditional respect for the laws of pollution prevention. Fortunately, it would appear that the very power of the atom has already played a part in encouraging respect for the dangers of radioactive contamination and pollution. This respect must be fostered and deepened so that all those responsible for the Public Health may gain a full understanding of the implications of the environmental dispersal of radioactive material.

Storage of waste

The development of nuclear energy for the production of power, the increasing uses of radioisotopes and the testing of atomic weapons all result in the production of radioactive waste. The waste may be liquid, solid or gaseous but, in whichever form, it can only be stored or dispersed. Storage is the most effective method of reducing the radioactivity of liquid or gaseous wastes containing short-lived isotopes. After a period of ten half-lives, only one thousandth of the original activity remains. This method is suitable, therefore, for manageable volumes of isotopes having half-lives up to a few weeks. However, the accumulation of long-lived radioactive waste in numerous small storage tanks distributed throughout the country would be a greater potential hazard than the dispersion of that waste in the natural environment at background levels.

Nuclear power production and the uses of radioisotopes involve the generation of only small quantities of " high level " waste but considerable volumes of " low level " waste. (No definition of high and low level waste based on activity concentration is available, the preferred criterion being the source from which the waste arises. Hence, wastes arising at a fuel element processing plant from the primary dissolution of irradiated fuel elements are high level. Wastes arising from wash down operations in a reactor area are usually low level.) The nuclear power programme and radioisotope usage would be both uneconomical and impractical if all the low level waste had to be stored. Concentration before storage is a possibility where small volumes of waste are involved, but for the large volumes resulting from the operation of a nuclear power station it would render the cost of the power produced wholly uneconomic. This in itself is not a justification for environmental dispersal of wastes; it is, however, a reason for examining the capacity of the environment to receive these wastes. As a result, dispersion in the environment of controlled quantities of low level radioactive wastes is seen to be a solution to the problem of their disposal because it is a natural and safe method. As with any type of toxic industrial waste, nuclear wastes should be discharged under rigorously controlled conditions.

Legislative control

Specific legislation has recently been passed in this country to implement effective control of radioactive waste discharges. The Radioactive Substances Act, 1960, requires that users of radioactive material shall be registered and shall obtain Authorizations for the storage or disposal of radioactive waste. In England and Wales the Authorizations are required from the Minister of Housing and Local Government and the Minister of Agriculture, Fisheries and Food. Before granting these Authorizations the Ministers shall consult with Local Authorities, River Boards and other public and local authorities appropriately concerned. In Scotland the Authorizations are obtained from the Secretary of State and in Northern Ireland from the Ministry of Health and Local Government and the Ministry of Commerce.

Similar procedures for obtaining waste disposal Authorizations must be followed by the Atomic Energy Authority, whose radioactive waste discharges are already controlled by the Atomic Energy Authority Act, 1954, and by users whose sites are registered under the Nuclear Installations (Licensing and Insurance) Act, 1959.

*This paper first appeared in the Journal of the Institution of Public Health Engineers.

The International Commission on Radiological Protection has recommended[1] maximum permissible concentrations for a number of radioactive isotopes in drinking water and in air. The calculations of these m.p.c's are based on the biological effects of ionizing radiations and the modes of uptake and excretion of the different chemical elements by the human body.

The biological effects may be distinguished as somatic or genetic. The somatic effects are those which affect the individual who receives the radiation dose and the genetic effects are those which affect his descendants.

Somatically, ionizing radiations delay mitosis of the undifferentiated cells and can destroy cells outright. Small radiation doses cause delay in mitosis, but after irradiation there is recovery and the rate returns to normal. Larger doses cause degenerate cells to appear and, if the dose has been sufficiently large, the number of degenerate cells prevents the repair process from taking place since there are insufficient normal cells available for recovery. Hence, after low doses recovery is possible and larger total doses may be absorbed over a period of time than if they are received at one moment. Examples of somatic damage due to radiation are induction of cancer, dermatitis and cataract.

The genetic effects of radiation are the result of the action of ionizing radiations on the chromosomes. Additional gene mutations may be caused or the chromosome linkage may be broken. Any rearrangement of the chromosomes and genes will be repeated in future cells arising from subdivision. If the reproductive cells are irradiated, the rearrangement will vary the hereditary characteristics. The result of genetic damage would be impairment of bodily or mental function in the descendants of an irradiated individual, though this impairment may not be manifested in the immediate offspring.

Gene mutations take place also from a variety of natural causes and may or may not be advantageous to the individual. However, man has developed through the years into a form highly adapted to his environment and the majority of mutations tend, therefore, to upset this adaptation. The result of increasing the number of mutations is thus to increase the number of harmful changes and to produce more individuals with characteristics less suited to their environment. In a steady population and as a result of natural mutations, there is always a certain number of these unsuited individuals and, by a process of natural selection, these tend to die young or are unable to reproduce their own kind. The proportion of unsuited individuals in a population is referred to as the genetic load. An increase in the rate of gene mutation will, therefore, increase the genetic load in a population.

Background radiation

The dispersal of radioactive wastes in the environment is an addition of radioactivity to an environment already " contaminated " by natural causes. We are all exposed continuously to natural ionizing radiations. These radiations originate from two separate sources, the igneous rock material in the centre of the earth and the cosmic rays from outer space. From these two sources of radioactivity the whole of our earth and all that lives on it has been contaminated since the earliest time.

The possible consequences of radioactive waste dispersal against which we have to guard are the biological effects of very low levels of radiation additional to the natural background. It is therefore necessary to know the radiation doses received from various natural causes and the ways in which these can vary in different circumstances. Only then can any increase which might arise as a result of waste disposal operations be assessed in true perspective.

The sedimentary and metamorphic rock formations are both derived from the igneous and, therefore, are also radioactive. One fraction of the soil is the product of rock weathering and disintegration and thus the soil, plant life feeding on the soil and all that feeds on plant life has become radioactive. The plants die and decay to form the humus fraction of the soil which is then totally contaminated.

Rainfall leaches the soil and carries radioactivity in solution and on suspended particles into the rivers. The rivers flow into the sea and thus both rivers and the sea contain a background of radioactivity. By eating crops and drinking water men and animals thus incorporate in their bodies small quantities of radioactive material.

The total dose received from background radiation is assessed by considering the four major contributions. These are the radiation received directly from the rock and soil, radiation from building materials, cosmic radiation and our own internal radiation. Differences in rock formations and in altitude affect significantly the background dose-rate received. Extreme variations in this country indicate maximum dose-rates 5 times the minimum, while in the world as a whole variations by a factor of 100 are found.

A number of radioisotopes occur in nature. However, many emit only weak radiations which do not contribute significantly to the total background dose-rate. The constituents of granite rocks which give rise to significant external gamma radiation are potassium, thorium, uranium and radium. The concentrations of these radioisotopes in rock vary considerably from place to place on earth and Table 1 shows the approximate dose to the gonads received from typical rock types.

TABLE 1

Background radiation from typical rocks

Rock type	Radioisotope	Dose-rate (mr/yr)
Granite	Potassium-40	40
	Thorium	40
	Uranium, Radium	20
	Total	100
Sedimentary	Total	20

Because much of the material used in building is obtained from the ground, some additional background radiation comes therefore from the walls and floors of houses. This contribution is clearly most significant in cities, where buildings are densely packed together and surfaces are fully paved. A study of the background gamma radiation in a house in Aberdeen constructed from local granite showed a dose-rate of 102 mr/yr compared to 78 mr/yr obtained in a house in Dundee

where bricks and mortar were used in the construction[2].

Cosmic radiation consists of a stream of charged particles and neutrons released in the upper atmosphere by the action of high energy alpha particles and protons incident from outer space. Much of the energy of these particles is spent in penetrating further through the atmosphere, so that only a small proportion reach the ground surface to contribute to the background dose-rate. There is, therefore, a considerable increase in cosmic radiation with altitude and this is shown in Table 2 where approximate dose-rates are given for various altitudes. In certain parts of the world large populations live at altitudes of 20,000 ft and, therefore, receive a greatly increased background dose-rate due to the increase in cosmic radiation. A study group of the World Health Organization is at present investigating these areas in an attempt to determine whether there is an increased rate of gene mutations in the populations[2].

TABLE 2
Background radiation from cosmic rays

Altitude (ft)	Dose-rate (mr/yr)
Sea level	35
5,000	50
10,000	100
20,000	400
50,000	4,000

There is also some variation in the intensity of cosmic radiation with latitude. The charged particles in the cosmic stream tend to be deflected towards the earth's poles by terrestial magnetism and thus give rise to slightly higher levels of cosmic radiation at higher latitudes. This increase is probably not more than 10 per cent. between the equator and the poles.

The last significant component of background radiation is the internal dose-rate received from the radioactive material metabolized into our bodies through taking in food, liquids and air contaminated as already described in the general environment. The main contributor to our internal dose is potassium-40 which constitutes 0·0119 per cent. of all naturally occurring potassium. The specific activity of natural potassium is such that it emits on average 28 beta particles/gm/sec and 3·6 gamma rays/gm/sec of 1·45 MeV energy. The dose-rate resulting from this and other internal radioisotopes is shown in Table 3.

TABLE 3
Background radiation from internal radioisotopes

Isotope	Radiation	Dose-rate (mr/yr)
Potassium-40	Beta	17
„	Gamma	2
Carbon-14 Radium-226	Beta Alpha	1
	Total	20

The total background radiation to which we are exposed is, therefore, the sum of the external radiation from the rocks and the cosmic rays and the internal radiation from radioisotopes deposited within the body. Typical values of the total dose-rate under various conditions are shown in Table 4.

TABLE 4
Total background radiation

Altitude	Typical granite (mr/yr)	Typical sedimentary rock (mr/yr)
Sea Level	155	75
5,000	170	90
10,000	220	140
20,000	520	440
50,000	4,120	4,040

The environment, therefore, already contains a natural contamination level of radioactivity and it is against this background that any increase caused by the disposal of waste must be measured.

Environmental dispersion

The discharge of gaseous waste into the atmosphere and of liquid waste into an infinite body of receiving water are comparable. (An infinite body may be described as one so large that boundary conditions do not impart any direct influence on the natural dispersal process.) Both are discharges of a fluid which subsequently is dispersed in an infinite volume of a similar fluid. In both cases the waste is dispersed in its receiving medium in two stages. These are referred to as initial dilution and turbulent diffusion and are distinguished by the source of the energy causing dispersal. In addition, particular fractions of either form of waste may be preferentially withdrawn from the dispersing medium by physical or biological action and reconcentrated in or on environmental material.

In conventional waste disposal, the dispersal mechanisms are usually adequate to reduce the concentrations of objectionable constituents in the effluent below harmful levels. However, the maximum permissible concentrations of most radioisotopes are so low that in radioactive waste disposal the environmental reconcentration is a most important factor. Consequently, every possible advantage needs to be taken of the natural dispersal processes. An examination of these processes reveals criteria which are of value in siting the discharge point.

Initial dilution

Initial dilution of a waste takes place immediately after discharge from a chimney or pipeline as a result of the dissipation of the energy in the effluent stream. This energy is largely kinetic and is very quickly converted into the energy of the turbulence set up in the surrounding air or water. Finally, it is dissipated by shear which mixes the boundaries of the effluent plume with the diluting medium.

The initial dilution is usually of short duration occurring within the first seconds after discharge. Nevertheless, it is a highly significant stage in the dispersal process. Particularly is this so in the discharge of liquid effluents into the sea, since there results an initial vertical distribution of the effluent plume in the receiving medium. The energy subsequently imparted to the plume by natural causes such as the wind and the tide is seldom sufficient to cause such rapid vertical movements and dispersion in the vertical direction is less readily achieved than in the horizontal direction. The efficiency of dispersion may be considerably influenced, therefore, by the design and siting of the discharge point.

Turbulent diffusion

The motions of the effluent plume would cease once the energy imparted before discharge was spent, were it not for the addition of further energy from external sources. In the natural environment such forces are almost always present due to the influence of the sun and the moon on the earth's surface. Wind and tide maintain

the air and the sea in a state of continual movement and this produces turbulent diffusion.

While it is possible to predict an overall pattern of currents due to the flow of air and water, innumerable smaller eddies are formed completely at random and no method has yet been devised for pre-determining their size or their direction. It is these eddies which are responsible for the second stage of the dispersal process and a quantitative assessment of the dispersion which they will produce can only be made by experimental studies of a particular case. Since conditions vary each time, it is necessary to conduct trials for every new site where discharges are proposed. These trials are best performed on the full scale in order to overcome uncertainties due to scale effects. However, this involves the expense of the full scale structure before its worth has been proved and model tests, which yield much useful preliminary information, are frequently carried out.

The eddies create turbulent conditions in which their directions vary continuously within the overall influence of a current movement. Dispersion of an effluent plume coming into this turbulence is by turbulent diffusion. This is not strictly analogous to molecular diffusion, though attempts have been made to compare the two by introducing very large values for the coefficient of diffusion represented in Fick's Law:

$$\frac{\delta Q}{\delta t} = -k\frac{\delta c}{\delta x}$$

where:

- $\frac{\delta Q}{\delta t}$ is the rate of diffusion of substance through 1 sq.cm;
- k is the coefficient of molecular diffusion;
- $\frac{\delta c}{\delta x}$ is the concentration gradient along the normal to the surface.

In molecular diffusion transfer of dissolved substances occurs down the concentration gradient and is proportional to that gradient. The value of k is of the order of 10^{-6} sq.cm/sec. The mechanics of turbulent diffusion are different and involve the exchange and translation of whole masses of water in the directions of the turbulent eddies. As the eddies vary in size and direction, so do the masses of fluid and their directions of translation. The coefficient of turbulent diffusion varies considerably with the size of the eddy and may range from 1 sq.cm/sec for eddies of about 3 ft in length to 100 for eddies extending to about 300 ft[3].

Turbulent diffusion is, therefore, a long term process. Theoretically it continues until the concentration of the waste discharged is uniform throughout the infinite mass of receiving fluid—that is until infinite time. The rate at which turbulent diffusion takes place is entirely governed by the rate at which energy imparted from natural sources is dissipated in the formation of eddies. Therefore, judicious siting of the waste outlet may also assist materially the second stage of dispersal.

Gaseous wastes

The dispersion of gaseous waste discharged to the atmosphere takes place in two stages, therefore—firstly by initial dilution and secondly, by turbulent diffusion. However, as has been seen, the initial dilution is a direct result of the conversion of kinetic energy immediately after the gas leaves the outlet point. Since the mass of a gas is low, its kinetic energy is also low except at high discharge velocities and these occur only in exceptional circumstances. Consequently, dispersion is generally achieved far more significantly by eddy diffusion than by initial dilution. Further, since the initial energy of the gas is low, the effluent plume is particularly subject to external influences characteristic of the outlet conditions. The one which affects the initial dilution most significantly and detrimentally is downdraught.

Under ideal dispersion conditions, a gas discharged from a chimney will be less dense than air and will rise vertically into the atmosphere. It will continue to ascend becoming more and more dilute with increasing height as turbulence at the edges of the plume creates mixing. Unfortunately, these ideal conditions very rarely occur. Usually, a wind blowing across the top of the chimney stack deflects the gaseous plume downwind, the deflection becoming greater with increased wind velocity. At high wind velocities effluent plumes may be observed to trail horizontally downwind from the top of a stack.

Downdraught

As the wind passes round a stack, its velocity tends to increase due to the smaller local cross-sectional area of flow through which the air must pass. There is thus an addition of kinetic energy to the air stream which is offset by a reduction of pressure energy in the lee of the chimney. An effluent plume emerging from the top of the stack may be drawn into this low pressure region if its exit velocity is insufficient to overcome the deflection caused by the wind. This effect is known as downdraught (Fig. 1). Observations on chimney stacks frequently reveal a blackening of the stack wall on the side in the lee of the prevailing wind. The frequency of downdraught is a function of the exit velocity of the gaseous waste and the frequency of winds having velocities high enough to deflect the plume into the low pressure region.

In a similar manner, the wind passing over and round the building on which the chimney is constructed also causes turbulence on the lee side and, because of the greater restriction to the flow of the wind, this is considerably more extensive than the chimney turbulence. When a stack is sited on top of a building, therefore, there is a danger that the effluent plume, having been drawn down into the stack turbulence will be further carried right to ground level by being brought into the region of building turbulence.

The nature and cause of downdraught have been investigated by Sherlock and Stalker[4] at the University of Michigan. They found that a pattern of vertical and horizontal vortices were formed downwind from the stack. These were responsible also for bringing the effluent to ground level. The waste gas was channelled through the open upper ends of the vortices into the turbulent region behind the building and thence by mixing was brought to the ground.

In addition to the local turbulences caused by the low pressure regions behind the stack and the building, large scale downdraughts may be formed by the environmental topography. These also cause swirling and further turbulence contributing

to the tendency for the effluent plume to be brought down to ground level. Partly resulting from the topographical effects is the non-uniformity, or gustiness, of the wind itself. This also induces turbulent flow patterns which are wholly unpredictable due to the variable nature of the wind currents.

It is important, therefore, that the frequency of downdraught conditions should be reduced to a minimum. A number of procedures may be employed, though all are costly. A rule used successfully for a number of years by the electricity industry in attempts to overcome downdraught is that the height of a chimney shall be at least two and a half times the height of the highest adjacent building[5]. When the chimney is sited in hilly country, or among buildings which make it impracticable to apply the two and a half times rule, wind tunnel tests on models must be carried out to determine where to site the chimney and how high to construct it in order best to avoid downdraughts.

The variation in wind velocity is a natural phenomenon which cannot be overcome, but for a given wind velocity there is a critical discharge velocity above which downdraughts will be avoided. Experiments at the University of Michigan[4] showed that for wind velocities up to 15 mile/hr the critical discharge velocity is approximately 1·5 times the wind velocity.

In certain circumstances a further means of minimizing the frequency of downdraughts is to discharge the waste gas hot. The thermal lift thus given to the gas helps to overcome the winds blowing across the top of the stack. It is usually impracticable and uneconomic to add heat to a waste gas for this purpose but, on occasions, it is possible to conserve heat by lagging until the gas is finally discharged to the atmosphere.

The sum effect of the exit velocity and the thermal lift will effectively increase the stack height, so that it becomes possible to define an effective stack height which may be considerably greater than the actual stack height.

Assuming that the waste gaseous plume is able to escape from the top of the stack without becoming affected by downdraught, subsequent dispersion in the atmosphere is by turbulent diffusion. A number of attempts have been made to rationalize the flow patterns which arise after discharge from a stack. In general, these attempts are based on observations of a few particular discharges under specific conditions. The work of O. G. Sutton[6,7] is notable and has been shown to give good estimates of ground level concentrations resulting from stack discharges in all except inversion conditions[8]. Two principal equations arising from Sutton's theory of gaseous diffusion from a continuous point source are:—

$$X_{max} = \frac{2Q}{\pi e u h^2} \cdot \frac{C_z}{C_y}$$

$$d_{max} = \left(\frac{h^2}{C_z^2}\right)^{\frac{1}{2-n}}$$

where:

X_{max} = maximum ground level concentration downwind from the chimney (units/cu.m)

d_{max} = distance from the chimney to the point of maximum concentration downwind (m)

Q = discharge from the chimney (units/sec)

h = chimney height (m)

u = wind velocity (m/sec)

e = base of natural logarithms = 2·718

n = a coefficient accounting for the stability of the air (dimensionless)

C_y = Sutton's virtual diffusion coefficient in the cross-wind direction ($m^{\frac{1}{2}}$)

C_z = Sutton's virtual diffusion coefficient in the vertical direction ($m^{\frac{1}{2}}$)

Values of the constants under average conditions given by Sutton are shown in Table 5.

Thus estimates of the maximum concentration which will occur at ground level and the distance of this point downwind from the point of release can be made. These estimates assume release under steady conditions. However, the wind direction varies around all the points of the compass. The estimate of long term concentration in any segment subtended by the chimney may be reduced, therefore, according to the frequency with which the wind blows into that segment from the stack.

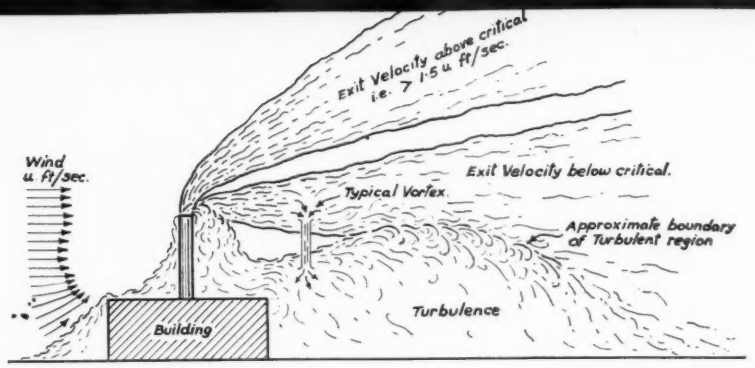


Fig. 1—Effect of downdraught on discharge from stack

TABLE 5

Values of Sutton's constants under average conditions[7]

n = 0·25; u = 5 m/sec.
(for zero or small temperature gradient)

h (metres)	C_y (metres $^{\frac{1}{2}}$)	C_z (metres $^{\frac{1}{2}}$)
0	0·21	0·12
10	0·21	0·12
25	0·12	0·12
50	0·10	0·10
75	0·09	0·09
100	0·07	0·07

Under inversion conditions, however, there is no established agreement between values of X_{max} and d_{max} calculated from Sutton's equations and those found in practice. The waste gas rises vertically through the denser cold air until it reaches the base of the overlying warm air layer. Being now colder and thus more dense than the air above, the plume can rise no further, but spreads out downwind in a horizontal band. Further cooling of the plume due to its proximity to the cold air increases its density and thus facilitates turbulent diffusion downwards into the cold air region. The presence of an inversion layer thus restricts diffusion into the upper atmosphere and tends to return the waste gas to ground level. Where possible discharges should be made at sites where the frequency of inversions is a minimum and the inversion layers tend to be highest.

Liquid wastes

On being discharged into an infinite body of surrounding water, a liquid effluent is also subjected to initial dilution and turbulent diffusion. The pattern of flow during the period of initial dilution is dependent on the relative densities of the effluent and the receiving water. When an effluent is discharged horizontally into a body of fresh water which has a density insignificantly different from that of the waste stream, the initial dilution will continue so long as the effluent still retains energy in excess of that of the receiving water and provided boundary conditions do not upset the natural flow pattern. However, if the effluent is discharged horizontally into the sea, buoyancy forces immediately act on it and are proportional to the difference in density between the effluent and the sea water. The plume rises to the surface in a curved path and then spreads out radially from its axis (Fig. 2). With the added energy derived from buoyancy, the initial dilution may thus not be completed at the time the plume hits the surface. In order to obtain the maximum benefit from initial dilution, the outlet should be sited, therefore, in the deepest possible water.

M. L. Albertson *et al* have described[9] initial dilution as taking place in two stages. These they have defined as the zone of flow establishment and the zone of established flow (Fig.2). In the first, the velocity difference between the effluent and the surrounding water is overcome by shear and mixing progresses both inwards and outwards from the boundary of the plume. The zone of flow establishment is defined as persisting until the axial velocity of the plume V falls below its efflux velocity V_o, mixing then having penetrated to the centre of the plume. At this stage, shear effects reach a maximum due to a continuous decrease in velocity across the whole of an enlarged section of flow and give rise to optimum mixing conditions. Subsequently, in the zone of established flow, the shear effects become increasingly reduced as the velocity distribution becomes more uniform. When the mean velocity of the plume, now considerably enlarged by entrainment of the surrounding water, is equal to that of the surroundings, further mixing is by turbulent diffusion. The dilutions obtained in the different zones are[9]:

Zone of Flow Establishment:

$$\frac{Q}{Q_o}=1+0{\cdot}083\frac{x}{D_o}+0{\cdot}0128\frac{x^2}{D_o^2}$$

Zone of Established Flow:

$$\frac{Q}{Q_o}=0{\cdot}32\frac{x}{D_o}$$

where:

Q=the rate of flow of effluent past a section distance x from the efflux section;

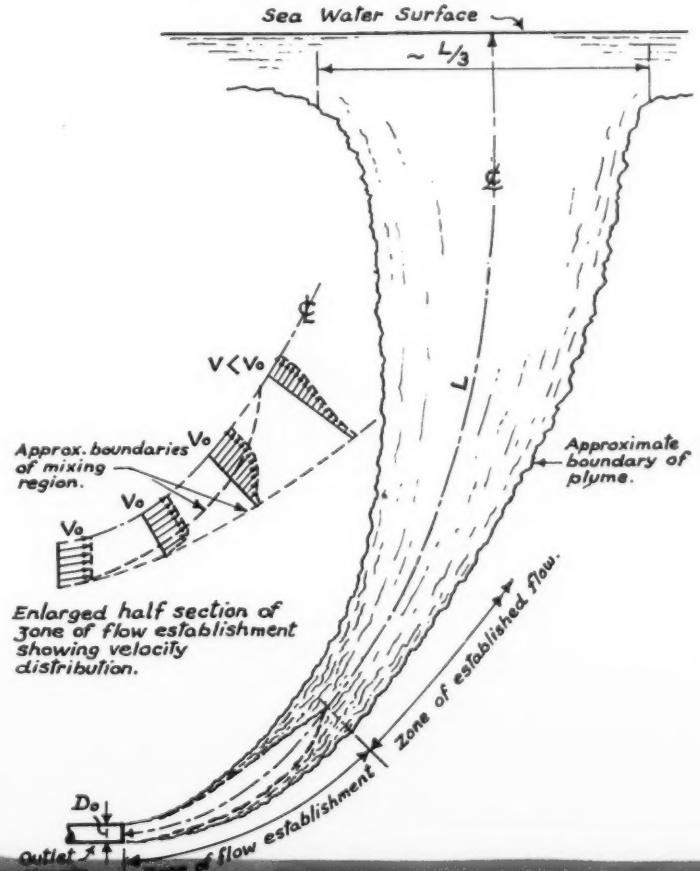
Q_o=the rate of flow of effluent past the efflux section;

D_o=the orifice diameter.

A number of investigators have confirmed that the initial dilution depends only on the path length, x, and the orifice diameter, D_o, for turbulent flow.

It is advantageous, therefore, to discharge the effluent horizontally along the sea bed in order that the path to the surface is curved and thus longer than that resulting from vertical discharge. A significant increase in the effective path length may also be obtained by the use of multiple orifices in the end of the pipeline, though some overlapping between the separate effluent plumes may occur. Rawn and Palmer have shown[10] that the diameter of the surface "bubble" resulting from the use of a single orifice is about one third of the path length from the orifice to the surface (Fig. 2). Therefore, for a path length of 90 ft the diffusers ideally should be spaced at 30 ft centres to prevent interaction. Usually, closer intervals are adopted allowing some overlapping of the plumes near the surface.

Fig. 2—Initial dilution of effluent discharged into sea water



Turbulent Diffusion

In the natural environment of the sea, water movement is nearly always turbulent. Although there may be an overall flow pattern resulting from tidal or wind effects, the motion of individual water masses of all sizes is at random, and an accurate picture of the dispersion pattern at any particular site can only be obtained by experimental studies.

The turbulence of a water mass is a measure of the energy it contains and the characteristics which determine its turbulence are the average velocity of the water molecules within the mass, the average velocity gradients which are proportional to

the shearing stresses and the size of the mass itself. The water masses move randomly within the main body of water carrying with them these characteristics and at each movement there is some loss of energy due to viscosity or the shearing effects with neighbouring water masses. It is the exchange of water masses which causes the dispersion of the waste in the sea and the rate of exchange, and hence the rate of dispersion, is proportional to the rate of loss of energy by turbulence.

An instantaneous picture of the velocity pattern would give a random distribution of values and, so far, no method has been developed of obtaining such a pattern and thus of predicting the rate of exchange of the water masses.

Stratification

However, it is convenient to make a distinction between horizontal and vertical turbulence. The eddies may be in any direction but it is their horizontal and vertical components with which we are concerned. The horizontal exchange of water masses, that is, the horizontal diffusion, is very considerably in excess of the vertical since movement in the vertical direction must overcome gravitational forces. In addition, if due to temperature or salinity differences, the density of the water increases with depth a water mass moving downwards will be less dense than its new surrounding water and will tend to rise again. Similarly, water moving upwards will have a tendency to sink back to its former level. This stratification will considerably reduce eddy diffusion in the vertical direction. In some circumstances the horizontal eddy diffusivity has been found to be several orders of magnitude greater than that in the vertical direction[11].

Since the dispersion is proportional to the degree of turbulence in the surrounding body of water, the site of a discharge point should be such that the horizontal turbulence is a maximum and, if possible, the vertical turbulence is also significant. Considerable assistance towards the maintenance of fully turbulent conditions in the vicinity of an outlet may be obtained by siting it in a tidal stream and in as exposed a position as possible in order to benefit from the maximum wind effect.

Reconcentration

When an effluent has been discharged into the environment it is no longer under man's control. Its movement is governed by natural processes and it is distributed through the environment by the dispersing medium into which it was discharged. It may collect on inorganic material or in or on dead or living organic matter. While the waste remains in the dispersing medium it is likely to be least harmful, because its concentration is being continuously reduced by the dispersal processes. However, its attachment to other substances involves a concentrating process, in which specific fractions of the waste are accumulated by physical or biological action on selective surfaces or in selective cells.

It is customary to measure the pollution caused by " conventional " industrial wastes in terms of parts per million. However, concentrations of 1 p.p.m. of some radioisotopes in drinking water, for example, would give concentrations 10^{11} times their respective maximum permissible concentrations. A comparison of the maximum permissible concentrations of stable and unstable isotopes in drinking water is given in Table 6. Stringent limitations are necessary, therefore, on the uptake of radioactivity by environmental materials and, hence, on the discharge of radioactive wastes to the environment.

TABLE 6

Maximum permissible concentrations in domestic water supply

Isotope	MPC of radioisotope (p.p.m.)	Limiting conc. of stable chemical (p.p.m.)
F^{18}	$3{\cdot}3\times10^{-12}$	1·5
Cr^{51}	$7{\cdot}4\times10^{-9}$	0·05
Fe^{55}	$1{\cdot}4\times10^{-7}$	0·3
Fe^{59}	$4{\cdot}2\times10^{-10}$	
Cu^{64}	$2{\cdot}6\times10^{-11}$	3·0
Zn^{65}	$1{\cdot}3\times10^{-9}$	15
I^{131}	$5{\cdot}1\times10^{-12}$	3
Pb^{210}	$1{\cdot}5\times10^{-9}$	0·1

Environmental concentration of non-radioactive isotopes discharged in conventional waste occurs all the time. However, the limiting concentrations in environmental materials are rarely reached. Because the maximum permissible concentrations of radioisotopes are so very much lower, any tendency for their accumulation and concentration in the environment is a serious problem.

Concentration of radioactivity direct from an effluent plume on to inorganic material is a physical process (unless an organism acts as the agent of deposition). This concentration is the result of adsorption on to the inorganic particle surfaces and the degree of adsorption is related to the surface characteristics and the state of the isotope. Concentrations of activity in dead organic matter may also be the result of adsorption or may have been absorbed when the organism was living. Decomposed organic matter generally has a greater capacity for adsorption than inorganic material owing to its cellular structure. Concentration in living organisms probably takes place in two stages. The isotope is thought to be first adsorbed on to the interface between the cell and the surrounding fluid and later absorbed into the cell structure by metabolic processes.

Uptake

A considerable number of variables are involved in the reconcentration processes. For a given material, different isotopes have markedly differing concentration factors and rates of uptake. Their chemical states and their concentrations also influence their uptake. For example, phosphorus-32, which is essential to all living cells, is taken up quickly by algae living in water in which there is a phosphorus deficiency. The addition to the water of stable phosphorus in an available form such as phosphate reduces both the rate of uptake and the concentration factor of the radioactive phosphorus in the algae. On the other hand, uranium present in the water will not be concentrated by absorption into the algae.

For a given isotope, different concentration factors operate on differing materials, because of the effects of their varying surface characteristics and their differing metabolic requirements. Thus, estimates of concentration factors which may be expected under any particular set of circumstances can be based only on previous experimental evidence and not on any theoretical calculations.

Radiological control

The reconcentration of minute quantities of radioactive material from effluents necessitates a very close watch on the different routes by which this material may be returned to man's immediate environment. Whether any hazard to the public will result from a radioactive waste discharge depends on the ways in which the environment, or any environmental materials, are used. These uses and the materials available differ from place to place and it is necessary, therefore, to conduct independent environmental surveys in the vicinity of every proposed discharge.

The environmental survey must reveal all the routes by which the discharged activity may be returned to man. It must also provide sufficient information to enable calculations to be made of the maximum permissible concentrations of the constituents of the waste on all the relevant environmental materials. The investigations must take into account the possibilities of both external and internal radiation. (External radiation is that incident on the body from an external source. Internal radiation arises from radioisotopes deposited in the body following inhalation or ingestion.)

The calculations of the maximum permissible concentrations are based on the Recommendations of the International Commission on Radiological Protection. These give maximum permissible external dose-rates[12] and maximum permissible concentrations of individual radioisotopes in air and water, which would give rise to maximum permissible dose-rates in the internal organs[1]. These dose-rates are additional to natural background and to any radiation which might be received from the medical uses of X-rays and radioisotopes.

In assessing external radiation dosage, consideration is given to the concentrations of isotopes at the source, the types and energies of the radiations emitted, the proximity of an individual to the source and his time of exposure, and any shielding which might effect a reduction of the radiation intensity. In this case, the external dose is fixed by the ICRP Recommendations and the required information is the concentration of activity at the source which would give rise to that dose. The individual's proximity, time of exposure and shielding will be dependent on the particular circumstances under consideration and values are taken which are representative of the more extreme cases of exposure.

Internal radiation problems are assessed by considering the concentrations of isotopes at the source and the manner and extent to which the source material is used. Here, the concentration of the isotope required from the calculation is that which will result in a total intake no higher than the maximum permissible. The maximum permissible intake is obtained from the ICRP Recommendations by multiplying the daily intake of the standard man (2×10^7 ml of air; 2,200 ml of water) by the appropriate maximum permissible concentration for the isotope in air or water. The maximum permissible concentration of the isotope in the source material is then obtained by dividing the daily intake rate of the source material into the calculated maximum permissible daily intake of the isotope.

e.g. for a given isotope:

$$\text{MPC in ingested environmental material} = \frac{\text{MPC in water} \times 2{,}200}{\text{Daily intake of environmental material}}$$

These calculations allow only for radiation from a single source. Where irradiation may be both external and internal and arises from a number of sources, the maximum permissible concentration at each source is reduced so that the total dose received from all sources does not exceed the maximum permissible.

Maximum permissible concentrations are calculated for every isotope which is to be discharged on all the environmental materials concerned. A preliminary discharge of these isotopes at very low levels is then accompanied by a programme of environmental sampling and analysis to determine the uptake of the radioactivity on the various routes to man. For any isotope, the sample material with an activity concentration which is a greater proportion of its maximum permissible than any other is then the critical material for that isotope, and would be the first to limit the discharge rate if this were increased indefinitely.

When the critical materials for each isotope have been established, operational discharges are carried out in such a manner that the activity concentrations do not reach their calculated maximum permissible values. A continued programme of sampling and analysis is vital to ensure that safe conditions are maintained in the environment.

Conclusion

This paper has summarized the factors which have to be considered in the environmental dispersion of radioactive wastes. Many branches of science and engineering are immediately concerned with these problems and many variables are shown to be involved. Some of the ways in which an improvement in dispersal can be achieved are discussed and an outline is given of the methods of radiological control.

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Book Reviews

Nuclear Reactor Containment Buildings and Pressure Vessels, Royal College of Science and Technology, Glasgow. Published by Butterworth, 572pp, 100*s*.

On December 2, 1942, on a squash court on the campus of Chicago University, Enrico Fermi was ready to start his criticality experiment on what was to be the first controlled release of atomic power. On a platform stood a group of three men, the "suicide squad," who were to throw buckets of cadmium solution over the pile if anything went seriously wrong. A fourth man waited with an axe, to cut the rope holding the control rod. Ever since those days the question of safety has dogged the development of nuclear energy. As nuclear power reactors grew in size, the problems of control and containment have been steadily tackled. There may come a day when technology will be so advanced that the present day pressure vessels and containment buildings will appear as the results of very amateur groping in the dark. That day is still a long way off. The importance of the whole subject of reactor safety was high-lighted in May, 1960, when the First Symposium on Nuclear Reactor Containment Buildings and Pressure Vessels was held at the Royal College of Science and Technology, Glasgow. The choice of venue was a happy one, because of the long and illustrious associations of the College with industry and especially with nuclear engineering. The Symposium comprised six technical sessions, covering 22 papers, by British and American authors. These papers, together with open topic contributions and summaries of the proceedings, are the subject of this volume. Section 1 deals with current practice and future trends and contains four papers: in section 2 are five papers on design studies, and methods of stress analysis: section 3 has ten papers on analysis and experiment in shell research; finally, there are, in section 4, three papers on engineering design, fabrication, erection and testing. The reactors dealt with in this symposium were not only power developing types, but included research reactors and even the small educational reactors, which require no containment, were not overlooked. It is clear that nuclear power has reached a stage where improvement in capital costs is essential and reduction in costs by special attention to pressure vessels and containment buildings may well be possible. The discussions on the papers are particularly valuable from this point of view, introducing as they do many stimulating and challenging suggestions and arguments. There is still a great deal to be done and to be learned in this field and H. M. Finniston's remarks are very much to the point: "Most codes of practice for engineers are based on failures...in this kind of safety-minded technology, we are not going to see a sufficient number of failures occur which will determine our code of practice. We must do more experimental work out of pile, as well as in pile, to answer some of the questions if a code of practice is to come about." F.R.P.

Proceedings of the Second Conference on Reactions between Complex Nuclei, edited by A. Zucker, E. C. Halbert and F. T. Howard. Published by John Wiley and Sons, 319pp, 56*s*.

It seems a short time ago when Rutherford achieved the first man-induced nuclear disintegration. Yet accelerators, neutrons, nuclear fission, the hydrogen bomb and plasma physics have paved the road to progress in the study of nuclear reactions of increasing complexity and involving heavier and heavier nuclei. This trend in nuclear science was brought to a focus at Gatlinburg, Tennessee, in 1960 when a conference on reactions between complex nuclei was held. The 40 papers read to the 112 scientists from 30 universities, laboratories and other institutions varied widely in content and in nature, some being completed works, others informal lectures. The proceedings of that meeting are gathered together in this volume, which should prove invaluable to physicists and chemists in the heavy-ion field, but it will certainly appeal to a considerably wider readership. As stated in the preface, "the reader may at first search in vain for some common ground which justifies putting papers on subjects as diverse as coulomb excitation and fission in the same book...but he will discover... that it is the classical nature of collisions which gives this field an underlying unity." It would be invidious to single out any of these papers for special comment, although a few generalities are worthy of mention. The importance of the use of complex nuclei with high charges for coulombic excitation was exploited long ago, but as re-emphasized during this conference. Such excitation leads to a knowledge of the quadrupole transitions matrix element between rotational levels and the inadequacy of the shell model and its wave functions becomes clear. The high charges on complex nuclei make possible multiple coulomb excitation and the study of states with high angular moments, which should yield information on the range of validity of the "unified model" and "shell model" theories of rotational bands. Nuclear reactions in distant collisions, of which $Au197 + N14 = Au198 + N13$ is an example, are an interesting series of phenomena for which alternative mechanisms have been proposed. In close collisions, the two nuclei combine to form a compound nucleus in the first place, followed by particulate emission. A wealth of new information arises on fission, a type of reaction which until recently was thought to have no inverse reactions. It seems probable that even before fission occurs, some neutrons or other light particles may be emitted. Experiments on collisions of 160MeV oxygen nuclei with nickel and gold nuclei raise some fascinating and debatable points. Some of the work described in this volume shows clearly how much still has to be learned before the reactions between complex nuclei are fully understood. The reader will find in these many papers a large number of stimulating aspects, some baffling problems and plenty of room for thought. F.R.P.

Fast Reactors by R. G. Palmer and A. Platt. Published by Temple Press, 83pp. Price 12*s*. 6*d*.

It is a sobering thought that man's technological advances are not in step with his ability to live in peace with his fellows, so that it is Utopian to talk of an era when plutonium will be available in plenty for peaceful purposes. Should such a time ever arrive, the fast reactor should prove successful in producing economic power from plutonium. Such an advanced type of reactor is not simple and its development bristles with difficulties. High burn-up and high power density imposed by economic considerations require enriched fuel, fuel elements which are both costly and complicated, non-moderating coolant with good heat transfer, suitable canning materials and so on. These in turn introduce new problems of core design, mass transfer and corrosion, rapid and extensive swelling of fuel elements, difficulties of compatibility between canning materials and coolant, the large amounts of heat liberated even after shut-down and the very real possibility of core melt-down. Needless to say, there are also economic considerations. This book, to my mind, is one of the most sucessful of the series of Nuclear Engineering Monographs and the authors have presented an amazingly vivid and interesting survey of a difficult subject in such a way that this modest-sized volume should prove a worthy contribution to the standard literature of the nuclear industry. The authors, faced with the task of covering such a vast field have nevertheless presented a very logical and concise account of the tackling of all these problems. In their introductory chapter they discuss the place of the fast reactor in nuclear power development and the programmes so far undertaken in the U.K., U.S.A. and U.S.S.R. Details are given of the features peculiar to fast reactors to be found in the core reflector, coolant circuits, shielding and containment. In a chapter on materials we find a reasoned account of the choice of fuels, coolants, cans and structural materials. The choice of liquid metals was an obvious one and sodium has such outstanding advantages that it has warranted a special chapter covering control and measurement of oxygen content, heat exchangers, moving parts, bearings and various types of pumps, including the electromagnetic and mechanical types. Chapter IV deals with fast reactor statics, neutron cross sections, neutron transport, diffusion equations, perturbation theory, and experimental studies. The next chapter, on fast reactor dynamics covers delayed neutrons, reactivity response, reactivity feedback, temperature and power coefficients, resonance, oscillators, stability and analogues. The final chapter is a short but masterly treatment of heat transfer in liquid metals, which even taken by itself would be well worth a careful reading by every engineering student. An adequate bibliography, 30 well-drawn figures and a number of valuable data tables, help to make this little book an invaluable *vade mecum* for the student of reactor engineering. F.R.P.△

Isotopes and Mixing Problems

by F. R. Paulsen

IN many industrial processes it is important to know how to obtain the most economical mixing, or when thorough mixing or homogenization has been achieved. Chemical analysis has long been used for checking these points, but it may often involve lengthy processes. Radioisotopes have brought a rapid, simple solution in many cases.

If one of the components of the mixture is labelled with a radioactive material, then the examination of aliquots at various time intervals will enable one to see whether the radioactivity is uniformly distributed or not. Sometimes a continuously-operating monitor may be employed.

It is possible to purchase hundreds of radioactively-labelled compounds nowadays, or special ones may be made to the customer's requirements. In some cases a chemically identical radioactive species is not required. For example, if a solid and a liquid are to be mixed, then any radioactive material soluble in the liquid could be added, provided it is not likely to be adsorbed on the surface of the solid, or evaporated in the mixing process. Powders are best labelled with an identical, but radioactive, component, but it is sometimes possible to use another radioactive powder of similar particle size and density.

Strong emitter

If the added or tracer material is a strong gamma emitter, then it is usually possible to measure its radioactivity even through the walls of the mixer or container, or through pipes, and aliquots need not be taken. In this case the scintillation counter is best used. A short-lived isotope should be used, so that the mixture will soon become marketable.

Sometimes gamma labels are not possible. In this case beta emitters may be added to the mixture. Here self-absorption in the sample becomes important and larger samples may have to be taken. When continuous readings are to be taken it is better to use a weaker emitter. One big advantage of the radioactive tracer technique is that only minute amounts of the added material are necessary because of the very high sensitivity of the detector.

There are many industrial processes in which this radioactive label technique can be employed. A few examples may be quoted here.

In tackling the problem of some 3m. tons of silt which are carried down by the Thames every year, the Port of London Authority used radioactivated glass powder and mixed it with mud, then dropped it into the water. Radioactivity was measured in the mud of the river, the port and the estuary, and the results indicated clearly that much silt was being carried upstream from the estuary by tidal waters.

Tritiated water

Tritiated water (T_2O) has been used in studying the mixing properties of water in problems connected with disposal of sewage, trade effluents and radioactive wastes. This particular labelling material has the great advantage of being chemically identical with ordinary water, so that it is not preferentially adsorbed on water-borne mud particles or ingested and metabolized by aquatic creatures.

Much use has been made of tracers in Soviet metal industries. Thus, Calcium-45 and Phosphorus-32 have been employed in metal melts so that these elements may very quickly be determined in the finished products, without the need for lengthy chemical analyses. Similar techniques have been used for estimating the weight of metal in a ladle. Also it may be employed for the identification of steel ingots in rolling mills.

Chromium-51 has been used to find the melting rate of ferrochrome in an open-hearth process, while both Sulphur-35 and P32 have been employed for studying the kinetics of the removal of these two elements in the open-hearth process. For studying the rate of mass transfer in open-hearth furnaces, Cobalt-60 and Cr51 have been used.

Mechanism of slag formation has been elucidated by means of tracer techniques, using Sodium-24, Ca45, S35 and P32. The nature and origins of slag inclusions in steel have been studied by the use of radioactive calcium, sulphur and phosphorus. In blast furnaces, the flow of gases has been worked out using radioactive radon and krypton. Again, the crystallization of metals and the distribution of impurities in metals, have been successfully tackled by means of radioactive tracers.

The performance of grease-mixing machinery has been followed by using the isotope Iodine-132.

Complete constancy

In cracking plants for the manufacture of fuels, there may be feeds of different viscosity and density, which have to be blended. It is very important to ensure complete constancy of these properties in the blends. In one plant in the U.S.A. the blend was fed into a 50,000-barrel tank, with circulation through a loop pipe at the rate of 100,000 barrels a day. In spite of this, there were abrupt and severe viscosity fluctuations. An oil soluble compound of radioactive Zirconium-95 was added through one of the inlet pipes and the radioactivity of the oil in the stock outlet pipe was monitored by counters placed against the outside of the pipe. Moderate uniformity was found to be attained in a short time, but considerable fluctuations appeared in radioactivity for more than five hours. The degree of inhomogeneity was estimated from the readings.

In another plant, radioactive triphenyl stibine ($Sb(C_6H_5)_3$) was injected into the top of a vacuum distillation column and the activity measured at eight points around the circumference of a chosen tray. At only four points on one side of the column was there descent of the liquid, so that the column was obviously defective. This accounted for incorrect purity results obtained on the distillates. The radioactivity measurements were made outside the column, without any shut-down.

△△△

Nuclear Training and Research Equipment

by Otto F. Joklik

(*This article is continued from page 295 of our July issue*)

LET us now consider the high gain d.c. amplifier shown in Fig. 3 as a triangle with input and feedback resistors as shown.

e_1 is the input voltage, and e_3 the corresponding output voltage. e_2 is the potential at the input grid of the amplifier.

Then if the gain of the amplifier is $-G$, we have:

$$e_3 = -Ge_2$$

$$\text{or } e_2 = \frac{e_3}{-G}$$

Thus if G is very large (it is in fact of the order of 10^7) e_2 may be considered as virtually zero by comparison with e_1 and e_3. Such a point is known as a "virtual earth."

By Kirchoff's first law, total current into any junction $=0$. Therefore:

$$i_1 + i_2 + i_3 = 0$$

Now the input impedance of a d.c. amplifier is extremely high, so that we may take $i_2 = 0$. Hence:

$$\frac{e_1}{R_1} + \frac{e_3}{R_2} = 0$$

$$\text{or } \frac{e_3}{e_1} = -\frac{R_2}{R_1} \quad . \quad . \quad . \quad . \quad (1)$$

This arrangement is used in the simulator to obtain $-n$ from n. If we replace a feedback resistor R_2 by a capacitor C, the equation $i_1 + i_3 = 0$ now becomes:

$$\frac{e_1}{R_1} + C\frac{de_3}{dt} = 0 \quad . \quad . \quad . \quad (2)$$

In the simulator this arrangement introduces the time-derivatives appearing in the kinetic equations.

In the basic electronic circuit (Fig. 4), only one delayed neutron network is shown. In the full circuit, however, there are six of these networks. Similarly, only one reactivity control, that for the control rods, is shown. The portion of e_1 selected by the potentiometer RV_1 is a, and this is variable from $(+1)$ to (-1).

Again by Kirchoff's first law, the sum of the currents flowing to the input of amplifier A_1 is equal to zero.

$$\frac{ae_1}{R_1} + C_2\frac{de_2}{dt} + \frac{e_3}{R_3} + C_1\frac{de_1}{dt} = 0$$

$$\text{Therefore } \frac{de_1}{dt} = \frac{-ae_1}{C_1R_1} - \frac{C_2de_2}{C_1dt} - \frac{e_3}{C_1R_3} \quad . \quad . \quad . \quad (3)$$

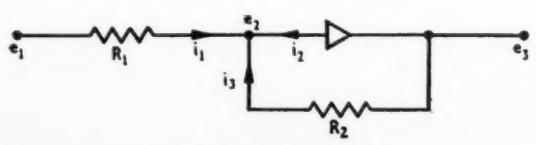


Fig. 3 D.C. amplifier circuit

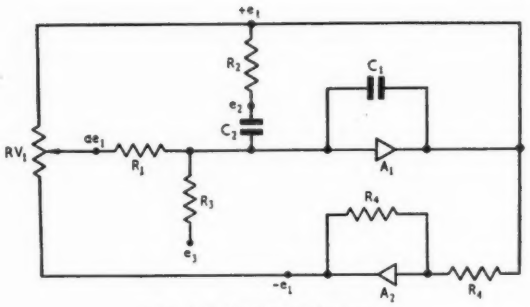


Fig. 4 Basic electronic circuit

The current in R_2 is equal to the rate of change of the charge in C_2:

$$\frac{e_1 - e_2}{R_2} = C_2\frac{de_2}{dt}$$

$$\text{Therefore } \frac{C_2de_2}{C_1dt} = \frac{e_1}{C_1R_2} - \frac{e_2}{C_1R_2} \quad . \quad . \quad . \quad . \quad (4)$$

If some of the constants in the electronic equations are made numerically equal to some of the constants in the reactor kinetic equations, then it will be seen that e_1 varies as n, and that e_2 varies as r_1.

In the equation (3) and (4) let

$$a = -\rho \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$C_1R_1 = \frac{\tau_0}{k\infty} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$C_1R_2 = \frac{\tau_0}{c\mu_1 k\infty} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$\text{Therefore } \frac{R_2}{R_2} = \frac{1}{c\mu_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$\text{let } C_2R_2 = \tau_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

$$\frac{e_3}{C_1R_3} = -S \quad . \quad . \quad . \quad . \quad . \quad (10)$$

Substituting equations 5 to 10) inclusive, in equations (3) and (4):

$$\frac{de_1}{dt} = \rho\frac{k\infty}{\tau_0}e_1 - \frac{C_2de_2}{C_1dt} + S$$

$$\frac{C_2de_2}{C_1dt} = c_1 c\mu_1\frac{k\infty}{\tau_0} - \frac{C_1e_2}{C_2\tau_1}$$

Substituting n for e_1 and r_1 for $e_2\frac{C_2}{C_1}$

$$\frac{dn}{dt} = \rho\frac{n}{\tau_0}k\infty - \frac{dr_1}{dt} + S \quad . \quad . \quad (11)$$

$$\frac{dr_1}{dt} = c\mu_1\frac{n}{\tau_0}k\infty - \frac{r_1}{\tau_1} \quad . \quad . \quad . \quad (12)$$

Equation (12) is equation (14) on page 293

Equation (11) may be deduced by substituting for $\frac{r_1}{\tau_1}$ from equation (14) in equation (13) on page 293

The controls and instruments discussed in this section are shown in Fig. 7, and are those used for operation of the simulator. These controls are mounted in the three-panel console.

Any other controls, *i.e.*, the setting-up controls at the rear of the simulator, and the switches in the pedestal cupboards, must only be set or adjusted by the demonstrator or service engineer.

Choice of reactor type

A neutron kinetic chassis is situated in the lower left corner of the console left-hand panel, under a hinged transparent cover. Mounted on this chassis are the controls which determine the type of reactor to be simulated.

The SOURCE control is a potentiometer which, in 10 complete turns, gives a reading from 0 to 100 MW equivalent.

The next two controls, a potentiometer and a key switch, are labelled EXCESS K which represents excess reactivity. The potentiometer controls the magnitude of the reactivity, and the position of the key switch determines whether the amount is added or subtracted. These controls are used to change the reactivity available in the reactor. They may also be used to provide step changes in reactivity.

Immediately below the source control is the FUEL SELECTOR switch. This is used to select the type of fuel to be used in the simulated reactor.

The remaining controls in the kinetic chassis are the PROMPT MEAN LIFE selector switches, which determine the lifetime of the prompt neutrons.

Mounted on the right-hand panel, underneath a hinged transparent cover, are three controls which enable maximum values of power level and rate of change of power and a minimum value of doubling time to be achieved while the reactor power level is increased to a predetermined level.

In addition to the above controls, a key switch AUTO SYSTEMS, A-B is used to select the transition from start-up to full power.

The reactor controls are mounted on the right-hand panel of the console. The reactivity is varied by control and shut-off rods, and safety rods. The appropriate set of indicator lamps at the top of the panel show green and amber when the rods are ready to be withdrawn and red when they leave the fully-in position. At intermediate positions between fully-in and fully-out, coarse and fine indicator dials show the position of the control and shut-off rods. The control and shut-off rods can be withdrawn only when the safety rods are fully-out. The latter are brought out by operation of the push-button labelled SAFETY RODS OUT and will continue to move only as long as the button is depressed, on manual control of the reactor.

When the safety rods are fully out, the control and shut-off rods can be moved by operating the handle at the bottom of the panel. The handle is biased to the central position and is deflected to move the rods. The rate at which the rods move is proportional to the angle of deflection of the handle. The handle when released will return to the central position and rod movement will stop.

On the left of the control rod handle is the CONTROL AND SHUT-OFF RODS RELEASE push-button; operation of this button releases the control and shut-off rods to partially shut-down the reactor. The change in

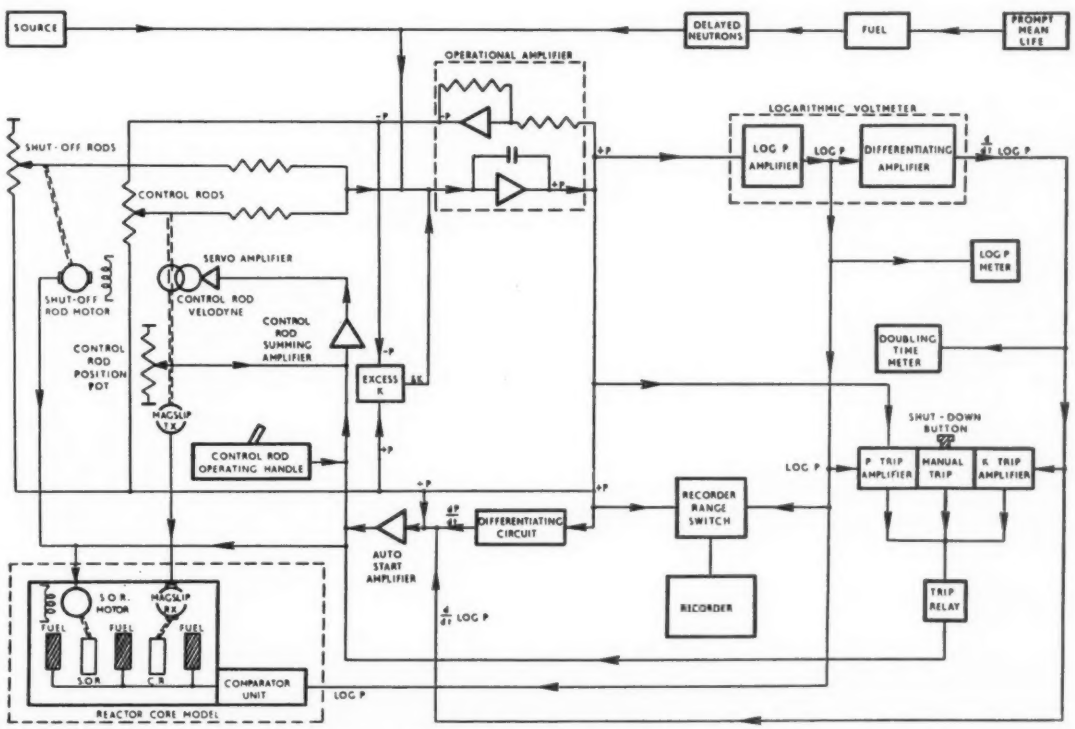


Fig. 5 Block diagram of simulator

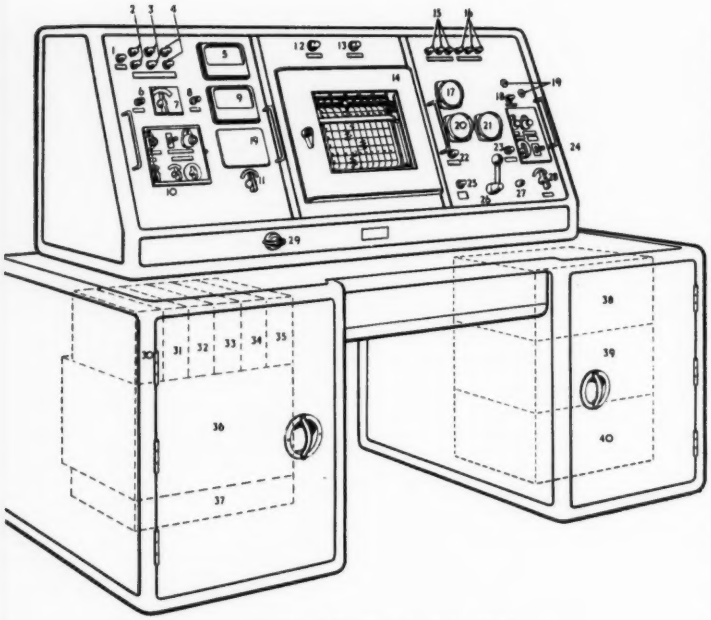


Fig. 6 Reactor simulator block

reactivity is instantaneous, and the coarse and fine dials return to zero. When the amber and green control and shut-off rod position indicators are illuminated the rods may be withdrawn again.

To shut-down the reactor completely, the push-button labelled EMERGENCY TRIP is depressed. In this case both sets of rods are released.

To operate the simulator on automatic control the MANUAL/AUTO switch is put to the AUTO position; the desired values of maximum power, rate of increase of power, and the minimum doubling time are then selected on the controls under the hinged transparent panel. The SAFETY RODS OUT push-button is depressed, momentarily, to bring out the safety rods and at once the cycle of operation begins.

The power output of the simulated reactor is continuously registered by a visual, single-pen recorder incorporating logarithmic and linear scales. This instrument occupies the centre panel of the control console. The front cover of the instrument, provided with a transparent observation window, can be locked to prevent unauthorized access to the indicator chart.

There are one logarithmic and four linear ranges on the recorder and these are selected by means of the RECORDER RANGE SELECTOR switch located on the left-hand panel. The logarithmic range covers six decades. The output power level is continuously displayed on a meter calibrated in watts on a logarithmic scale and located on the left-hand panel.

Doubling time is displayed on a meter located on the left-hand panel; the meter scale is calibrated in seconds.

Safety measures

The reactor simulator is provided with interlocks and trip warnings to give simulated safety guard against the following situations.

Accidental criticality; This danger might arise during the loading of a reactor if too much fuel were added.

In a nuclear reactor, safety rods are always kept in the ready position so that they would drop into the core to control such an event. In the simulator the interlocking system prevents control and shut-off rods withdrawal until the safety rods are fully removed. The simulated reactor cannot achieve criticality with a selected fuel load unless the safety rods are withdrawn and ready for reinsertion should an emergency arise.

Excessive power level and no power level; If the power level exceeds 90 kW, a reactor shut-down is effected by a safety trip. The reason for this is obvious. Should a nuclear reactor operator neglect to steady the power level after starting up, the temperature of the fuel might become too great; in any case, the radiation level outside the biological shield would endanger personnel.

The power level trip also operates if the flux measuring equipment indicates less than 0·2w. The neutron source in the reactor gives a shut-down power level which

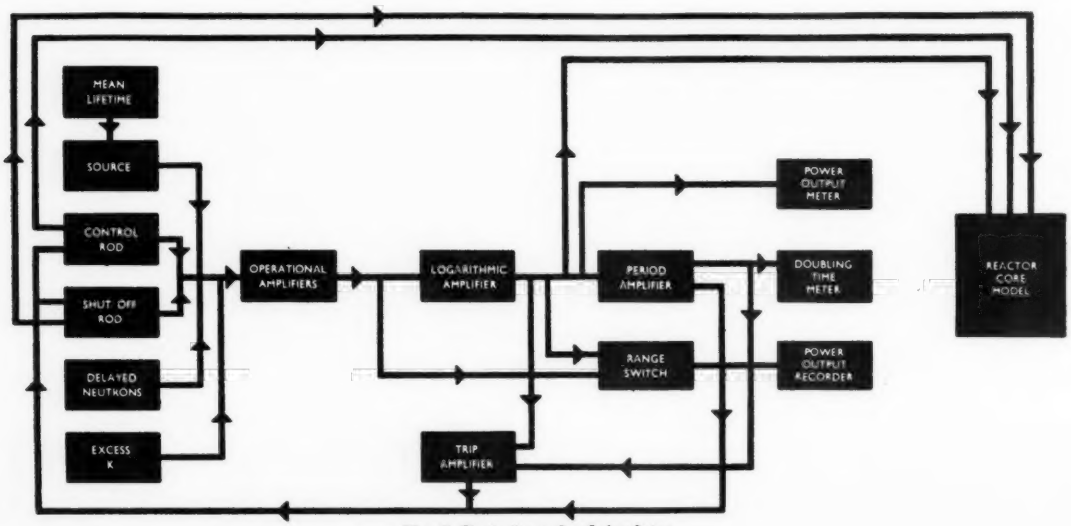


Fig. 7 Control panels of simulator

ensures that there is always a power signal to the equipment. If the instruments indicate " no power," then there must be an instrument failure, and a trip operates. This ensures that the reactor is never started up unless a power indication is being maintained.

Rapid rate of increase in power level; If, in a nuclear reactor, miscalculation is made at a low power level it is then possible for the power level to increase so rapidly that, although the power trip operates at 95 kW, unavoidable sluggishness of the measuring equipment and inertia of the safety rods may result in a short surge of power to many times that of the maximum power level. To avoid this, a lower limit to the doubling time is imposed; thus, when the doubling time becomes less than 5 sec, a " reactivity " trip operates.

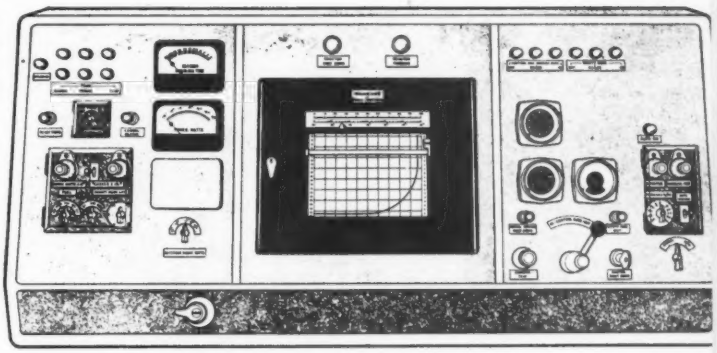


Fig. 8 Vickers Mk. 1A reactor simulator

Visual and audible warnings

The safety trips are indicated in the simulator by visual and audible warnings, using coloured indicator lamps and an alarm bell as follows: (*a*) A general REACTOR TRIPPED indication is given by a green light on the centre panel of the console; (*b*) Three red indicator lights labelled MANUAL, PERIOD AND FLUX, respectively, grouped at the top of the left-hand panel, indicate the cause of the reactor trip.

Operation of the doubling time trip illuminates the period trip warning, since an excessive doubling time is caused by too rapid increases of reactivity or by too high a value of reactivity.

Operation of a power level trip is accompanied by the illumination of the flux warning indicator light. All trip indications are accompanied by the ringing of the alarm bell.

When a trip has operated it must be reset before the reactor can be started up again. In the simulator this is accomplished by pressing the RESET TRIPS button, located immediately below the red indicator lights; if the cause of the trip is no longer present the trip warning indicator light will be extinguished and the green and amber indicator lamps for the safety rods will be illuminated if the safety rods are fully in.

The CANCEL ALARM button, also located beneath the trip warning lights, is pressed to silence the alarm bell. Either the PERIOD or FLUX trip may be overridden by use of the OVERRIDE switch. When a safety trip has been overridden a warning is given by the OVERRIDE warning light.

The reactor core model is designed for wall mounting It can be used in conjunction with the simulator or may be operated, for lecture or demonstration purposes, from a small electro-mechanical control box.

The model shows the cross-section of a graphite moderated reactor with shut-off rods, control rods and fuel elements and gives an indication of the events taking place within the reactor core. When used with the simulator, movement of the shut-off and control rods is slaved to the movement of those in the simulator. The fuel elements, control and shut-off rods are represented by coloured strip-lighting. The intensity of the light in the fuel element strips varies with conditions in the reactor, namely, bright at full power, black at shut-down.

A large range of experiments may be undertaken, and the facility is sufficiently flexible to cater for university and research requirements. Some of the basic experiments which Vickers Simulators have been designed to perform are outlined below:

Reactor start-up procedure: Simulation of reactor run-up. Approach to maximum power level. Step changes in reactivity. Doubling time and reactivity variations. Simulation of shut-down power level.

Other experiments of a more complex nature can be performed using variations of the basic controls, as for example:

Introductions of step functions of reactivity at various running-up power levels; variation of source strength with the reactor running at very low, or intermediate, power levels; simulation of " accident " conditions, *i.e.*, investigation of reactor safety problems.

Part II—Research Reactors

Many advances in nuclear science over the past 25 years have been made possible by particle accelerators, which furnish beams of electrons, protons, deuterons and alpha particles, and also serve as neutron sources. The unique advantage of the reactor for research is the magnitude of its radiation field, which consists primarily of neutrons and gamma rays.

The use to be made of the radiation field determines the basic requirements for a research reactor installation. There are two primary factors: (i) Experimental capacity—especially the volume of irradiation space and number of access channels or ports; (ii) Neutron flux—unless there is an absolute requirement, a compromise is possible between the flux level and the length of irradiation time. In other words, the same effect usually can be obtained from less radiation per unit time by increasing the exposure time.

Many fundamental investigations can be carried out with small, low flux reactors. Isotope production and radiation damage studies, on the other hand, are best accomplished with large-volume, high-flux units. A wide variety of experiments covering practically every field of science and engineering are being performed with research reactors and their number is continually increasing.

The design of research reactors, as of power reactors, can vary considerably with such factors as the type of fuel and the degree of its enrichment, the type of cooling used, and the moderating material selected. Some form of cooling is required, though for the lowest power

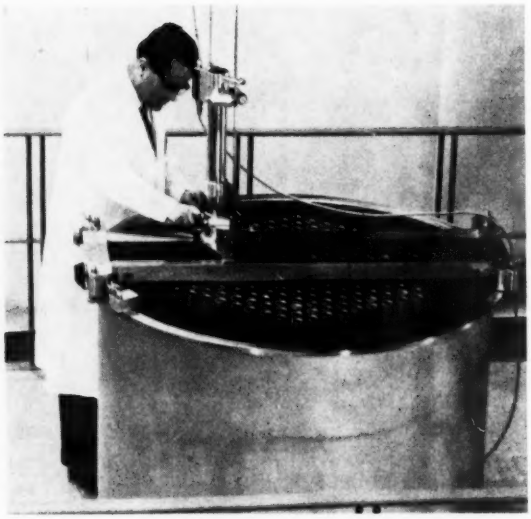


Fig. 9 Vickers training reactor

levels natural circulation can be employed. At any substantial power level, forced cooling must be used. Similarly, the fuel can be either fluid or solid, of almost any degree of enrichment. Among the various kinds of research reactors developed to date, there are five major types:

(1) The Solution Reactor, consisting of a solution of enriched uranium in a small sphere. This is a homogeneous reactor and is sometimes called " water boiler," though its solution does not get hot enough to boil. A boiling-like action is produced by the oxygen and hydrogen gases into which the water is decomposed by radiation.
(2) The Pool Reactor, consisting of a matrix of enriched uranium in solid fuel elements suspended in an open tank of water.
(3) The Light-water, Tank-type Reactor, consisting of a matrix of enriched uranium, solid fuel elements in a closed tank through which large amounts of cooling water are forced.
(4) The Heavy-water, Tank-type Reactor, consisting of a heavy-water-cooled matrix of enriched uranium, solid fuel elements in a closed tank.
(5) The Graphite Reactor, or graphite pile, consisting of a large, air-cooled, graphite structure, penetrated by fuel channels containing slugs of natural uranium.

The majority of research reactors operating or under consideration in the United States are solution or pool reactors. The light-water, tank-type reactor is a variant of the pool type designed for the specific function of materials testing.

The heavy-water, tank-type reactor combines generous experimental capacity and high flux with low critical mass. Though the initial investment is small, this type is receiving increasing attention and new projects are contemplated. The graphite reactor was designed before the widespread use of enriched fuel and is being supplanted by the other four types.

Advanced training in nuclear technology is made possible by training reactors with particular advantages for the teaching of nuclear physics and reactor core technology. The unique advantage of the Vickers Training Reactor described is the considerable flexibility of training and research in basic nuclear technology accomplished with this inexpensive instrument.

Vickers training reactor

The Vickers Training Reactor is a light water moderated natural uranium sub-critical assembly, designed by the Nuclear Engineering Section of Vickers-Armstrongs (South Marston), Ltd.

It is an ideal instrument for the teaching of nuclear physics and reactor core technology at University and Technical College level, and forms an inexpensive addition to the laboratory equipment of such educational establishments.

The assembly is offered as part of an integrated nuclear science and engineering training programme, and constitutes the nucleus around which may be assembled a versatile range of radiation measuring instruments.

Using natural uranium fuel, associated with a light water moderator, reflector and shielding, the assembly employs a polonium-beryllium source. A stainless steel tank of 340 gal capacity houses the nuclear core which consists of a hexagonal arrangement of up to 217 vertical fuel elements, contained in aluminium tubes. These are supported and aligned by means of two grid plates, which are arranged to permit automatic tube alignment to within 0·050 in. The provision of holes in the upper grid plate facilitates the inter-grid circulation of water acting as a reflector beneath the core.

Fuel elements consist of aluminium canned, natural uranium slugs. Secondary containment, provided by the

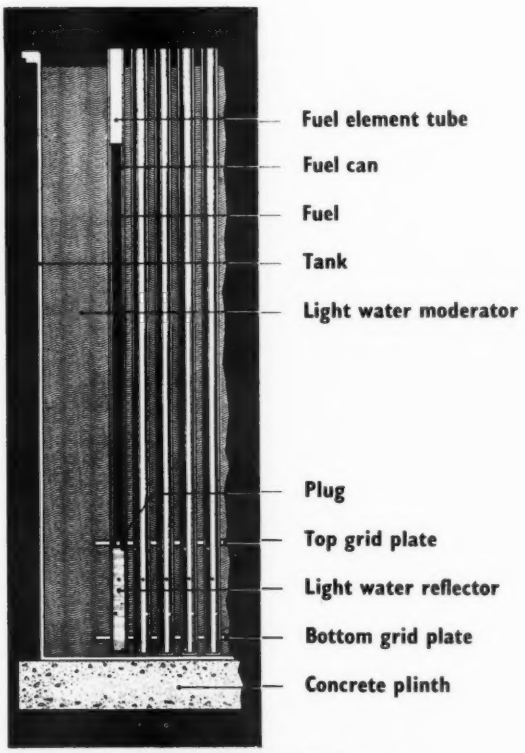


Fig. 10 Cross-section of reactor

aluminium tubes, prevents water contamination by uranium fission, and the hexagonal core assembly achieves advantages over a circular arrangement by maintaining homogeneity, in that the fuel elements are equi-distantly spaced.

The use of light water as a moderator, allied to the open construction of the assembly facilitates the insertion of foils, detectors and absorbers at any position within the core lattice, and generally provides ease of internal access for instruction, experimentation and maintenance.

The fission process in the lattice assembly enhances the neutron flux from the source by a factor of 9, but the power developed in the assembly is infinitesimal and the natural convection of the water moderator is more than adequate for cooling purposes.

Inherent safety is automatically ensured in a core assembly employing natural uranium, in conjunction with light water, and the fact that the assembly has a neutron effective multiplication factor less than unity prevents any possibility of the assembly reaching criticality. Close approximation of full scale pile characteristics relating to neutron distribution, multiplication scatter and reflector coefficients is assured.

The traversing mechanism is precision engineered to permit the location of the F.C.4 fission counter in any position in the lattice, and facilitates continuous automatic recording of vertical and horizontal neutron flux distribution.

Lateral position is determined by angular movement of the complete mechanism, and radial movement of the saddle which supports the probe. Angular movement is controlled to 1/100° by means of a vernier scale, and radial traverse is effected by manual operation of a lead screw which controls the lateral position to an accuracy of 1/100 mm.

The F.C.4 fission counter is mounted at the lower end of a graduated probe; vertical movement being obtained by a manually operated vernier graduated friction feed.

Rigid design ensures an essentially high degree of accuracy when the fission counter is operating at maximum depth.

Locks are provided on all traverse units to maintain consistency under operating conditions, and special attention has been paid to ease of unit attachment and removal from the assembly.

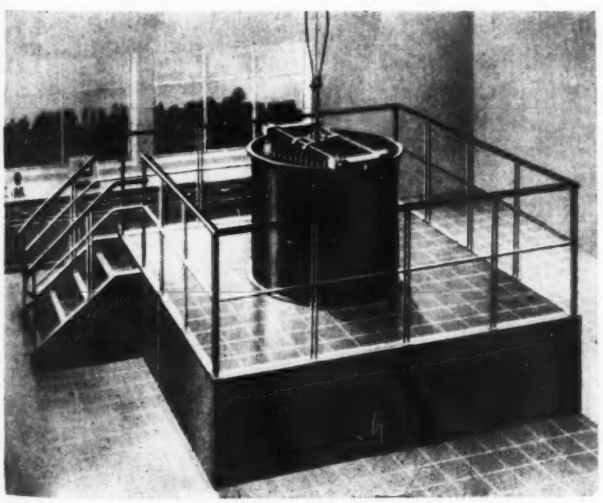


Fig. 11. Vickers training reactor

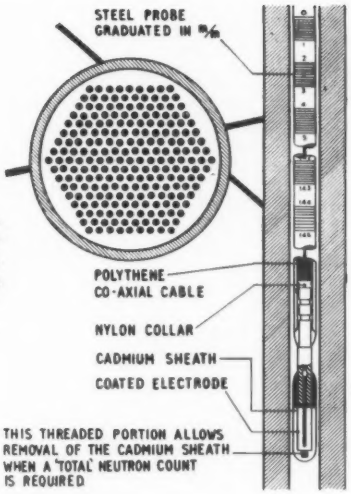


Fig. 12. F.C.4 U235-coated fission counter with detachable cadmium sheath and probe unit

The standard assembly is fully instrumented to cover a basic programme of over 30 experiments.

The Vickers Training Reactor represents special instrumentation suitable for schools which may be initiating or expanding their nuclear engineering and physics training facilities. It provides an ideal method of familiarizing students with experimental techniques.

Incorporation into training curricula is assisted by the provision of training manuals covering a comprehensive range of nuclear particle counting experiments, ranging from basic cosmic background determinations to neutron flux plotting, including both fast and thermal neutron flux counting by means of a U235-coated fission counter and a detachable cadmium sheath.

The standard assembly is fully instrumented to cover a basic programme of over 30 experiments and incorporates:

(1) Fast Dekatron Counter Unit—scaling factor 10^5—resolution time 50μsec.

(2) Register giving 10^4 additional scaling factor with resettable electro-mechanical counter.

(3) Automatic Timing Unit to permit both time-controlled counting and count-controlled timing.

(4) Regulated Power Supply Unit providing power for item 7 and EHT for GM tubes.

(5) GM Tube Mount and Sample Holder for end-window tubes, complete with lead shield and calibrated absorbers.

(6) Recording Ratemeter, incorporating pulse amplifier, discriminator, EHT safety circuits and chart recorder.

(7) Quenching Pre-Amplifier—*i.e.*, GM tube probe unit.

(8) Laboratory Ratemeter (Health)—General monitoring instrument fitted with an immersible helical cathode GM tube.

(9) One GM tube (MX. 123)—Halogen quenched, thin end-window type.

(10) An F.C.4, U235 coated fission counter with detachable cadmium sheath.

Items 1, 3, 4 and 6 are housed in an accompanying console which measures: height 3 ft 8 in., width 1 ft 10 in., depth 1 ft 6 in. The instrumentation can be accommodated on a standard laboratory work bench.

The assembly can be modified to meet any requirements and a wide range of ancillary instrumentation is available at an additional cost for the extension of the basic list of experiments.

The applied radiation research requires neutron and gamma irradiation facilities of various design. A flexible universal neutron and gamma irradiation facility is described below.

The Vickers Laboratory Source of Neutrons has been designed and developed to provide a safe and inexpensive item of laboratory equipment especially suitable for use by science students. The equipment is readily transportable and requires little space. A complete range of counting equipment is supplied with the neutron source.

The source is 10 millicuries of radium beryllium. Radium is a long life ($t\frac{1}{2}$=1,622 years) alpha and beta emitter. The alpha particles emitted by the radium react with the beryllium in the following (α, n) process:

$$_4Be^9 + _2He^4 \longrightarrow _6C^{12} + _0n^1 + 5{\cdot}71 \text{ MeV}$$

The source emits $1{\cdot}3 \times 10^5$ neutrons/sec and the gamma dose rate at 1 cm from the unshielded source is 84·4 roentgens/hr.

The main requirement is to shield against neutron and gamma radiations since these are most penetrating. The shielding for these primary radiations will be more than adequate to attenuate to a safe level any alpha and beta radiation emanating from the source.

Shielding is considerably aided by the inverse square law distribution of radiation emitted from a point source.

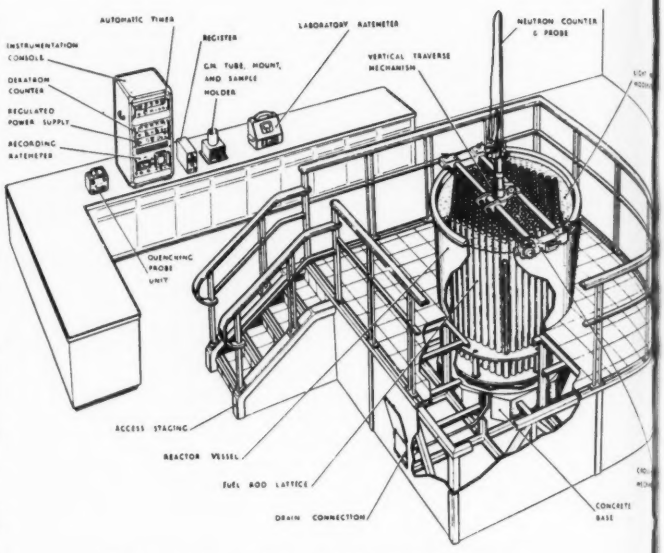


Fig. 13. Cutaway diagram of Vickers training reactor

At a distance of 42 in. from the unshielded 10 mc RA/Be source, an observer would receive less than a tolerance dose rate, *i.e.*, the maximum dose rate recommended by the International Commission on Radiological Protection for the continuous exposure of occupationally exposed personnel.

(This article will be continued next month)

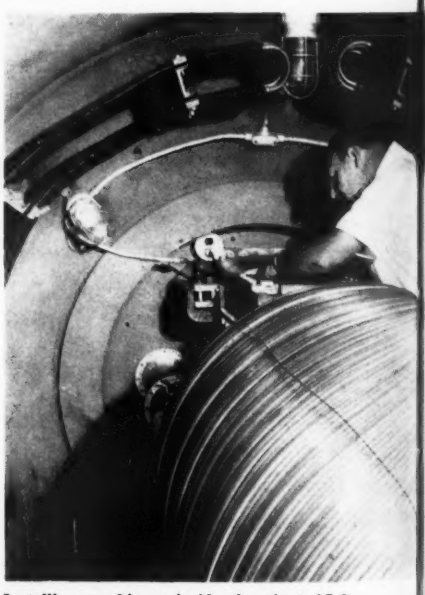
Versatile atom smasher for Australian University

THE most flexible and versatile atom smasher yet built for work in low energy nuclear physics is now in operation at the Australian National University in Canberra.

This atom smasher, a tandem electrostatic accelerator, is the fifth but largest of its type in the world and was built by the High Voltage Corporation of Burlington, U.S.A. It is housed in a laboratory 120 ft long and 62 ft wide, which was opened recently.

A giant 35 ft long, 8 ft diameter, 20 ton steel vessel, pressurized with more than 1½ tons of a dry nitrogen and carbon dioxide gas mixture, houses the main part of the new machine.

The head of the University's Department of Nuclear Physics, Professor E. W. Titterton, said that



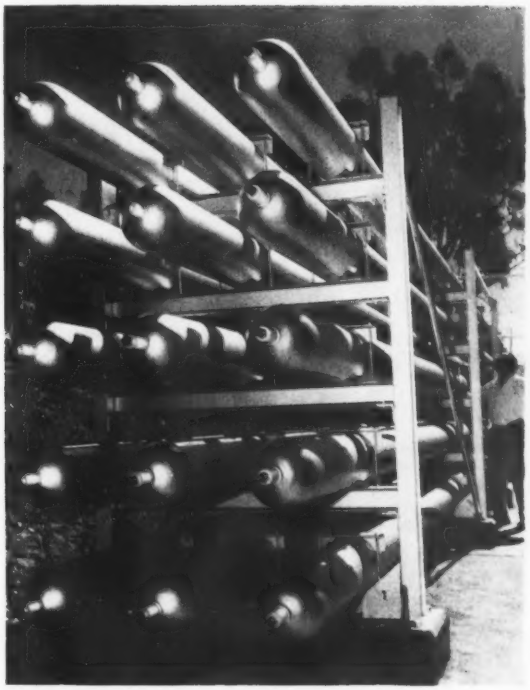
Installing machinery inside the giant 35-ft long steel pressure tube filled during operations with a mixture of 1½ tons of dry nitrogen and carbon dioxide gas to prevent bombarding particles from being scattered and lost

the new accelerator, added to three already in operation at the University, would greatly enlarge the field of experimental work in Australia.

Best equipped

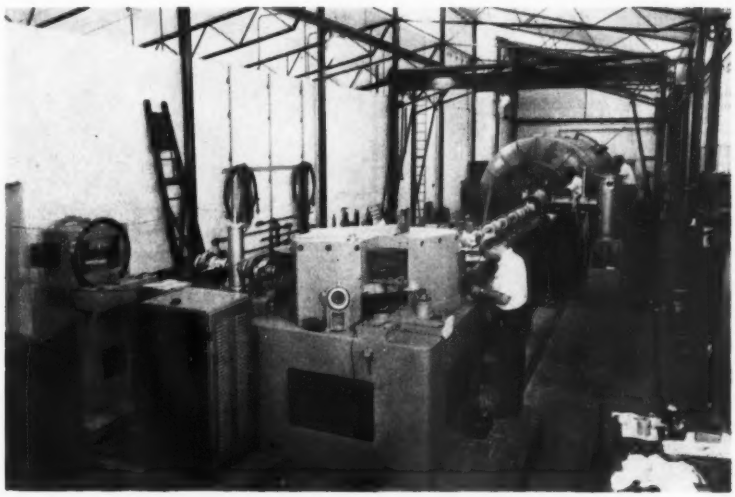
Completion of the new machine has made the Nuclear Physics Department of the University one of the best equipped laboratories in the world. Staff and students have been attracted from the U.K., the U.S.A., Canada, India, Sweden and New Zealand.

Talking about the new accelerator, Professor Titterton pointed out that nuclear physics aimed at studying the properties of all nuclei, both natural and artificial. In particular the physicist wanted to understand the nature of the exceedingly strong forces required to bind together the elementary particles, protons and neutrons, which were the " building blocks " from which all nuclei were constructed.



(*Right*)
Gas storage cylinders for replacing air in the accelerator pressure tube with a mixture of dry nitrogen and carbon dioxide

(*Below*)
The tandem electrostatic accelerator during assembly at the University



To do such work, he said, scientists needed atom smashing machines to make appropriate bombarding particles such as a proton, deuteron or α-particle and to accelerate them up to very high speeds.

The bombarding particles, protons, deuterons and α-particles, were made in a device called an ion source, from which they were fed to the accelerating machine which accelerated them through the influence of an electrostatic field on their charge. This was a process analogous to the acceleration of a body falling under gravity in a gravitational field.

There were many types of accelerating machines; some used electrostatic principles alone, others used electrostatic and magnet fields to achieve the acceleration. Some yielded only one type of bombarding particle, while others yielded bombarding particles of only one energy. But in most, the ion source was inaccessible to the experimenter, being buried in the centre of a magnet or in a terminal at a high voltage. According to Professor Titterton the great advantages of the new tandem accelerator at the Australian National University are that a wide variety of nuclei, including much heavier ones than those mentioned earlier, can be accelerated from an ion source which is readily accessible to the experimenter. Moreover, the energy can be varied smoothly from a low to a higher value by just turning a knob.

High precision

The precision with which the energy can be chosen and held is also very high—about one part in a thousand.

For example the machine in Canberra can accelerate protons to any energy from about 1½m.v up to 12m.v. At the latter value the bombarding particles travel at a speed in excess of 100m. mile/hr, and if allowed to leave the machine they would deliver their energy to the air, causing a bright luminous glow over a distance of 4 ft. Similarly, oxygen atoms could be accelerated to a maximum energy of 40m.v.

With this new accelerating machine it will be possible for the Australian National University to cause nuclear disintegrations in *all* available nuclei.

△△△

Annual Report for India . . .

INDIA'S rapid progress in the development of the peaceful uses of atomic energy is emphasized in the 1960-1 Report of the Indian Department of Atomic Energy. The commissioning of the Canada-India Reactor, providing a powerful facility for isotope production and of ZERLINA, an entirely Indian achievement, were given special mention.

The inauguration of these reactors with certain other facilities at the Atomic Energy Establishment was attended by prominent scientists and administrators from various countries. A symposium, which aroused great interest among scientists and public alike, was arranged in which lectures were given by representatives of the atomic energy organizations of Canada, France, U.S.S.R., U.S.A. and U.K.

The atomic power station to be located at Tarapur in the State of Maharashtra will produce about 300,000 kW of electric power and will consist of two nuclear reactors of equal capacity. Global tenders for the construction of the station have been invited and the first reactor is expected to be completed in 1965. As much use as possible will be made of Indian resources.

A project for the construction of a nuclear power station of about 20 MW (e), based on a reactor using natural uranium as fuel, heavy water as moderator and with an organic coolant, is expected to be started shortly. There is also the possibility of a station of 150 MW (e) in the Delhi-Punjab Rajasthan area.

The department has continued its policy of collaboration in this field with other countries and organizations and made useful and effective contribution at international meetings, where India is now recognized as the most advanced country in nuclear science and technology in the South Asian region.

Public interest in the work of the department and in atomic energy had stimulated public relations work. Contributing articles for technical and other journals, broadcasting and lecturing are a selection of the tasks undertaken by members of the Trombay Establishment.

Three documentary films were completed during the year in collaboration with the films division, namely "Canada-India Reactor, (CIR)"; "Search into Space," dealing with the balloon flights conducted by the Tata Institute of Fundamental research; and "From Tiny Grains of Sand," a documentary on the manufacture of fuel elements from materials derived from the beach sands of Kerala, showing the various processes involved. The department also participated in a number of exhibitions.

A vigorous search for atomic minerals is being carried out all over the country by the atomic minerals division which also is responsible for drilling, mining, stock-piling and conservation of atomic minerals. The main methods employed for geological investigation include: airborne and car-borne scintillometer survey; radiation jeep survey; geophysical survey; radiometric survey; magnetometer survey; and traverses with GM counters. △△△

. . . and Euratom

THE Fourth General Report issued recently by the Euratom Commission urges that more experience of the operation of atomic power stations be acquired. Since there is an insufficient number of nuclear power stations at present under construction in the Community, the Commission proposes to encourage the construction of power reactors of promising types by contributing towards the cost of manufacture of fuel elements, providing fuel and contributing to cost of reactor construction or underwriting the additional costs over those of conventional power stations. These proposals are now before the Community's Council of Ministers and already three companies—the Italian SENN and SIMEA groups and the Franco-Belgian SENA have made detailed requests for Euratom aid.

At the end of 1960 the total installed nuclear capacity of the Community was only 80 MW from reactors in France and Germany, but plans for power stations in France, Italy, Germany and Holland ensure that by 1965 the capacity will be 1,565 MW.

Limitations imposed by inadequate facilities and difficulties in the recruitment of suitable personnel have not hindered the expansion of Euratom's research activities. Altogether $50·4m. was earmarked for research in 1960, of which $30·7m. was being spent, while further research under way or planned will bring the total cost up to $165m. The opening of the Common Research Centre, together with the numerous contracts signed with national enterprises, has brought a major increase in research facilities.

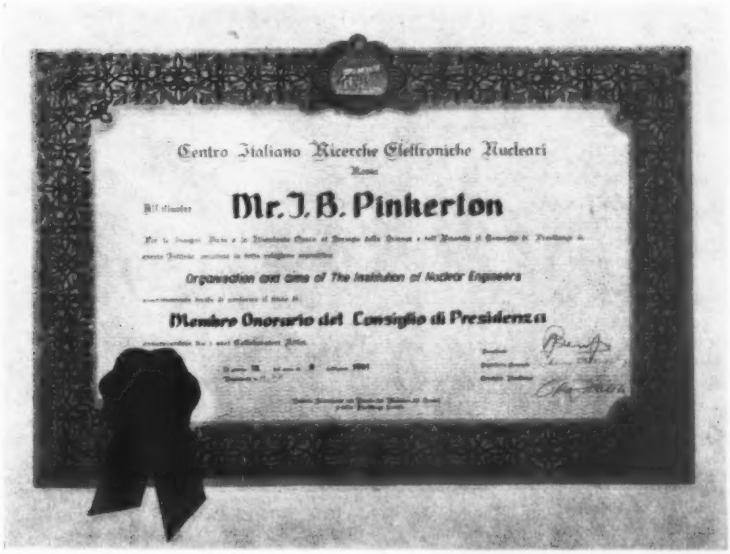
The year's research activities included expansion of the Ispra Research Centre, work on the Scientific Information Processing Centre, the Central Measurements Bureau and the Transuranium Elements Institute at Karlsruhe; and the conclusion of approximately 100 research contracts.

A total of $9m. is being used for nuclear ship propulsion studies, nine projects were being examined in the Community at the end of 1960.

The Report also comments upon Euratom's Supply Agency, the plan for the free movement of skilled workers in the Community, the new patent policy and the exchanges of information with the U.K. on fusion and health protection. △△△

Institution Secretary honoured in Rome

J. B. Pinkerton talks about our aims and objects


Centro Italiano Ricerche Elettroniche Nucleari
Mr. J. B. Pinkerton
Organization and Aims of The Institution of Nuclear Engineers
Membro Onorario del Consiglio di Presidenza

AT an impressive ceremony in Rome, attended by several hundred scientists and engineers, Mr. J. B. Pinkerton, secretary of the Institution of Nuclear Engineers, was invested with honorary membership of the Centro Italiano Ricerche Elettroniche Nucleari (the Central Italian Electronic and Nuclear Research Institute).

In addition to the illuminated certificate (illustrated here), he also received the Institute's gold medal, which has already been awarded to president Sir John Duncanson and vice-president D. S. Watt.

After the presentation, Mr. Pinkerton told the audience about the organization and aims of the Institution of Nuclear Engineers. "We have organized a special committee to collate material on teaching methods from all over the world and at the moment are engaged in preparing a number of seasonal lectures on various aspects of nuclear engineering and technology," he said. The Institution was also considerably interested in the use of nuclear energy as a fuel in space, and also in the biological aspects of space travel, as well as the treatment of disease by radioactive isotopes.

The accent of the Rome occasion was, in fact, "space" and special honours were conferred on notable astronautical personalities, led by Prof. Dr. Ing. Hermann Oberth, generally regarded as the father of astronautics, who received persistent attention from the many press and television journalists present. He was asked many questions about the biological aspects of interplanetary flight and the possibilities of (soft) landings on the moon.

Italians Welcome

DURING his visit to Rome, the secretary confirmed that all students who achieved the Diploma of the Centro Italiano Ricerche Elettroniche Nucleari would automatically qualify for associate membership of the Institution. △△△

(*Above*) **The secretary J. B. Pinkerton addresses the International meeting of CIREN in Rome on the aims and objects of the Institution**

(*Bottom left, left to right*) **Dr. Prof. Otto Joklik, vice-president CIREN, Dr. Prof. F. Wehrli, Dr. S. Schmidt, Dr. Prof. Hermann Oberth, Ing. Dr. Fritz Gerlach, Dr. Ing. Prof. Alessandra Banfi, president CIREN and Mr. J. B. Pinkerton, secretary of the Institution of Nuclear Engineers**

(*Below*) **An "electronic man"—a robot used for the remote handling of radioactive materials. It can be finely controlled from considerable distances and was made by CIREN students. Examining it on the left of the picture are Dr. Wehrli, Professor Joklik and Mr. Pinkerton**

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Dounreay problems

CAUSES of gas entrainment in the liquid metal coolant of the Dounreay fast breeder reactor have now been established and measures to prevent this in future are in hand. An alloy of sodium and potassium is used as coolant in this reactor and consequently the risk of the alloy oxidizing and catching fire is great. To reduce this risk the spaces above the coolant in the reactor are filled with nitrogen. During experiments at Dounreay changes in reactivity were observed, the cause of which proved to be the entrainment of bubbles of nitrogen in the coolant passing through the core. This problem is of considerable importance not only because of the changes in reactivity but also because of the danger of local hot spots occurring through the reduced effectiveness of the coolant. Tests were made to locate the source of the trouble and these showed that a reduction in the level of the liquid metal in the expansion tanks over the primary circuits was allowing gas to pass down a pipe which was normally filled with liquid metal. Further experiments showed that other causes of this trouble also existed, so additional instrumentation and viewing devices were installed. As a result of these experiments it was established that pressure drop was occurring at certain coolant flow rates in the vertical tubes forming part of the control rod mechanisms causing nitrogen to be drawn down the tubes into the main circuit. A similar effect also seemed to be occurring in the instrument thermocouple tubes which lead down into the core. It was discovered that the blocking of certain small pipes had caused the tank emptying effect and these are at present in the process of being cleared. Control rod and thermocouple tubes are being modified to alter their hydraulic characteristics by providing relief holes and baffles. The UKAEA state that results to date with the fast breeder reactor have been most encouraging; with the conclusion of the present modifications, the programme for raising the reactor power will be reviewed. The chemical processing plant for the fast reactor has successfully dealt with the first charge. Production and processing of the new fast reactor fuels still requires more chemical development work.

One of AMF's "Educator" reactors enclosed in glass and constructed on the campus at the University of Washington. The reactor, which recently went into operation, cost $½m. and will be used for training and research

Reactor for Pakistan

THE American Machine and Foundry Co. has been awarded an overall contract to construct a nuclear research reactor for the Pakistan Institute of Nuclear Science and Engineering in the new capital, Islamabad. The estimated cost of the project will be in the region of $8-10m. Work will be carried out at the Institute on training in uranium processing, fuel fabrication, theoretical nuclear physics, chemical engineering, health physics and electronics.

Problem solved

SPEAKING at a conference in Moscow, the eminent Soviet physicist Lev Artsimovich said there was no doubt that the problem of controlled thermonuclear reactions would be solved. He then said that although Soviet scientists had achieved successes, "we are still far from the set aim just as, incidentally, our colleagues studying this problem abroad are." Stressing the great future of atomic radio-engineering, which employed the laws of the atomic world in an absolutely new way, Lev Artsimovich, said so-called atomic radiostations may revolutionize communication engineering altogether. Each atom constituted a tiny radio station. Using this property of atoms and making them oscillate jointly and to the same rhythm, it would be possible to transmit a co-ordinated radiation flux. By means of these stations it would be possible to transmit signals far beyond the solar system, over distances running into thousands of millions of miles. He suggested that already within the next five or ten years atomic radio stations would take their place in practical life.

Savannah ready

ON COMPLETION of her present trial runs, the American atomic merchant ship *Savannah* is scheduled to enter limited commercial operations and then normal commerce. The ship which has been designed to run for 3½ years or 350,000 miles (almost 15 times around the world) requires 670 lb of atomic fuel. This has been derived from 22m. lb of uranium ore and was processed in two gaseous diffusion plants at Oak Ridge, Tennessee and Portsmouth, Ohio.

Soviet exhibition

AT THE Soviet exhibition in London, a 6 ft model of the atomic ice-breaker *Lenin* is on display showing a cross section of the reactor and machine compartments. Material on the *Lenin* is displayed and two wide-screen films, "The Giant of the Arctic" and "The Atomic Flagship" are being shown. This year the *Lenin* will be making its second voyage to the Arctic. Models of different types of atomic power stations with water-cooled and graphite reactors and fast neutron reactors are also featured at the exhibition as well as models of the "Alpha" unit, the world's largest magnetic trap "Ogra," and other nuclear research units. Considerable space has been devoted to the application of isotopes in the Soviet national economy. Samples of equipment using isotopes are displayed and visitors are able to learn how isotopes are being used in the U.S.S.R. A pulse ionization chamber for studying alpha-radioactive preparations which makes it possible to replace targets without disturbing the vacuum, a transistorized pocket radiation dosimeter and automatic instruments for examining radioactive wire are also on display at this exhibition which is one of the largest ever to be organized by the U.S.S.R. abroad.

Steel tube contract

A £300,000 contract for electrically-welded finned steel tube, for the Dungeness nuclear power station, has been awarded to Tube Products, Ltd. This follows contracts for similar extended surface tubing, to a total value of over £2m., placed with Tube Products for the Hunterston and Trawsfynydd nuclear power stations in the

NUCLEAR NOTES

U.K., the Latina project in Italy and the Tokai-Mura project in Japan. The company pioneered the development of this type of extended surface tubing some 3 years ago and has already supplied over 2m. ft of the material.

International co-operation

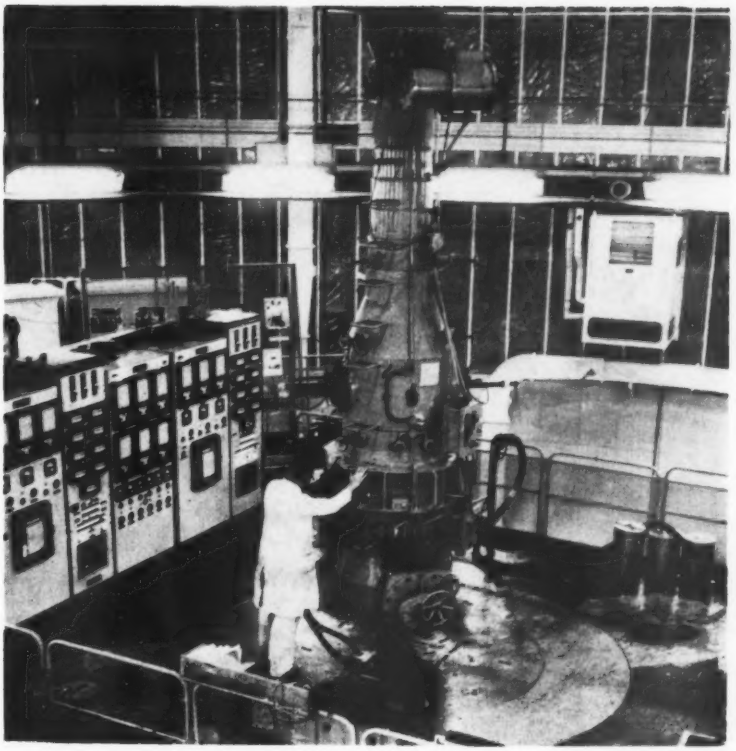
IN co-operation with other countries, Norway hopes to produce a nuclear-energy powered merchant vessel within five years. Present plans are based on building a 65,000 ton tanker, but a smaller bulk-carrier may possibly be built instead. Next month representatives from several European countries will meet in Paris to discuss these plans and to make the final decision. The cost will be an estimated £7½m.

New members

AUSTRALIA, Brazil, Canada, the Czechoslovak Socialist Republic, France, India, Japan, Portugal, South Africa, Sweden, U.S.S.R. United Kingdom and the U.S.A. have been designated members of the board of governors of the IAEA for 1961-62. The designation of members is based on a number of criteria, such as their advance in nuclear technology, their production of nuclear source material, as well as on considerations of geographical distribution. At present, the board consists of 23 members —13 designated by the board itself and ten elected by the Agency's general conference. Of the 13 members designated for the 1961-62 term, ten are members of the present board. The three new members are the Czechoslovak Socialist Republic, Portugal and Sweden; the outgoing members are Belgium, Finland and Poland. Under the statute, the Czechoslovak Socialist Republic and Portugal automatically follow Belgium and Poland. Of the ten members elected by the general conference, five—Argentina, El Salvador, the Federal Republic of Germany, Iraq and Thailand—will retain their seats for 1961-62. The terms of Bulgaria, Ceylon, the Philippines, Mexico and Spain will expire at the end of the forthcoming session of IAEA's general conference opening next September.

Cleansing plant

AN experimental plant for cleansing used uranium fuel, jointly operated by the Norwegian Atomic Institute and the Reactor Centre, Netherlands, was dedicated recently at Kjeller, near Oslo. The ceremony was attended by Dutch and Norwegian nuclear scientists and also by Dr. Gray, president of the Canadian Atomic Research Institute. The fully automated Dutch-Norwegian plant is operated by remote control to minimize radiation hazards. The work is conducted in close co-operation with one experimental and two analytical laboratories. The cleansing plant will be connected with a project for treatment of radioactive waste now under construction. The 35-member staff includes seven science graduates. JENER—the Norwegian-Dutch Establishment for Nuclear Research—was launched 10 years ago. Its Kjeller project includes JEEP 1, a 600 kW experimental heavy water and natural uranium reactor and a reactor school for university graduates.



Interior of the PLUTO reactor building at Harwell

Winfrith contract

THE UKAEA, acting on behalf of the OEEC Dragon project, have awarded the contract for the design, supply and installation of the instrumentation of the HTGCR being built at Winfrith, to Automatic Control Engineering, Ltd.

IAEA budget

THE 1962 Budget of the IAEA, prepared by the Agency's board of governors provides for a total expenditure of U.S.$8,316,000, which represents an increase of 4.4 per cent. over the total amount budgeted for the current year. The main feature of the budget is an increase in allocations for the Agency's substantive activities such as technical assistance, training, the holding of scientific meetings and dissemination of information and scientific and technical services to Member states.

Bradwell neutron sources

THE Radiochemical Centre at Amersham is making two neutron sources for the CEGB's twin-reactor nuclear power plants at Bradwell and Berkeley. Since these reactors will be starting up for the first time, thorium-228/beryllium sources will have to be used. Antimony/berylium sources are also being provided but they will be inactive and will only become effective some time after the reactors have been in operation. The thorium/beryllium sources consist of pellets made of an intimate mixture of compounds of the two metals trebly contained in welded stainless steel cans. When Berkeley and Bradwell have been operating long enough to activate their antimony/beryllium sources, it has been suggested that the thorium/beryllium ones—which will by then have decayed to about half their original strengths —should be removed, taken back to Amersham and combined there into a single source for the starting-up of Hinkley Point.

Chief scientist appointed

PROFESSOR Ilmo Hela, director of the Institute of Marine Research, Finland, has been appointed chief scientist in charge of the programme of research on the effects of radioactivity in the sea, to be conducted in Monaco under a trilateral agreement between the IAEA, the Government of the Principality and the Institute of Oceanography. Professor Hela is expected to take up his new appointment at the beginning of October this year.

Vienna symposium

METHODS of measuring the total amount of radioactivity in the body of a living person were reviewed at a symposium on whole body counting in Vienna recently. About 130 scientists from 26 countries and three international organizations attended the symposium organized by the IAEA.

NUCLEAR NOTES

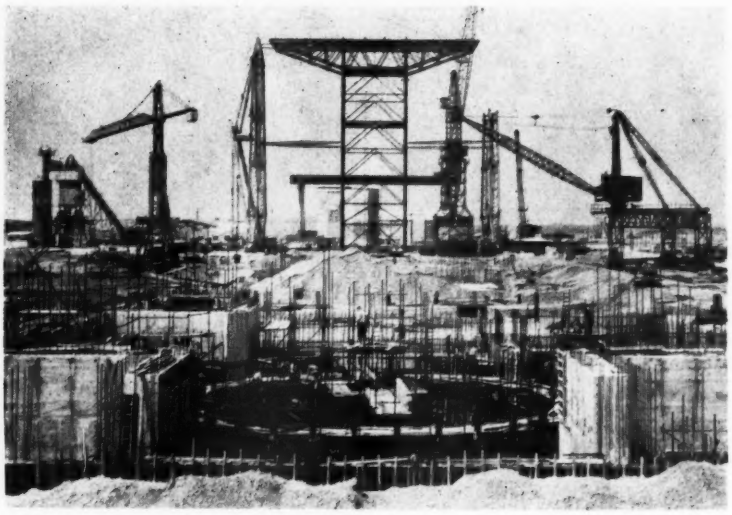
Extremely sophisticated techniques of whole body counting have been developed in measuring the total radioactivity in a living human. With regard to radioisotopic tracers, it is often necessary to find out how long an administered radioisotope is retained by the body. In recent years, there has been a remarkable development of the instruments and techniques for such measurements. One of the main purposes of the symposium was to discuss how best to use these elaborate instruments. Topics discussed included properties of radiation detectors, calibration techniques, typical whole body counting facilities, studies of natural and contamination burdens of radioactivity, data processing techniques and clinical applications of whole body counting.

Reactor for Japan

GENERAL Electric Japan, Ltd., have signed a contract to furnish a critical assembly reactor for the Japan Atomic Energy Research Institute. Design of the reactor and fabrication of the nuclear fuel will be carried out by U.S. General Electric. The reactor will be a light water moderated critical assembly utilizing uranium dioxide fuel enriched 2·6 per cent. with U235 and clad in aluminium. Scheduled for completion in July, 1962, it will be located at the Japanese nuclear research centre at Tokai Mura, about 50 miles north-east of Tokyo. Operating at very low powers up to 200w (thermal), the new reactor will be used in experiments to provide nuclear data for the design and evaluation of light water moderated and cooled reactor cores.

Break-even point

DR. R. B. RICHARDS, engineering manager of U.S. General Electric's atomic power equipment department, speaking at the recent American power conference said that with today's technology a standard 500,000 kW dual-cycle BWR plant can be built to operate in 1965 at a cost of about $175 (£63)/installed kW under favourable site conditions. In some areas this would compare favourably with fossil-fuelled power stations. A plant of this kind would initially produce power at 6·56 (about 0·56*d.*) mills/kWH, but this would decrease to 6 (0·515*d.*) mills/kWH beginning with the third core loading. These figures mean that power from such a plant would be comparable to power produced conventionally in areas of high fuel costs.



View of No. 1 reactor at Dungeness showing the retaining walls and shuttering for the biological shield in the foreground. To the rear is the Goliath crane and construction. Behind the Goliath is the boiler and pressure vessel fabrication area.

NORA tests

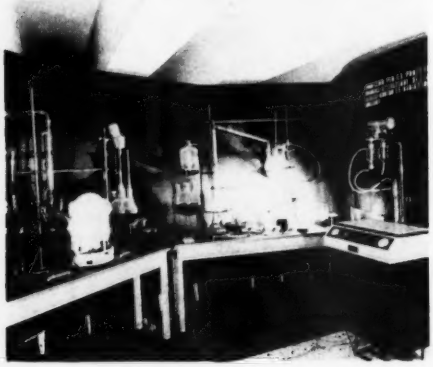
THE Norwegian Atomic Institute have started test operations of NORA, Norway's third new reactor which was built by A/S Noratom, Oslo and is located at Kjeller, near Oslo. It is staffed by eight scientists from different nations. The IAEA, Vienna and the Norwegian Atomic Institute will co-operate in a joint research programme at NORA. Experiments are expected to yield valuable data on design and operation of future reactor units. The U.S.A. has contributed £125,000 towards the £300,000 cost, which includes the purchase of about five tons of heavy water. In addition, the USAEC has made a reactor charge of 3 per cent. enriched uranium-235. Two additional uranium charges will be provided by Norway.

CNA meeting

THE Canadian Nuclear Association has now held its 1st annual meeting conference at Toronto. The whole of the proceedings of the conference have been included in a booklet published by the Canadian Nuclear Association which is available from the CNA, 19 Richmond St. West, Toronto 1, Canada, at a cost of $5 to non-members.

Indian point

THE nuclear power core—valued at $22m. —for America's largest stationary atomic electric generating station being built at Indian Point, New York, has achieved its first sustained chain reaction at the Babcock & Wilcox Co. atomic energy division laboratory in New York. The criticality test, conducted at the company's Lynchburg, Va., nuclear laboratories, confirmed all nuclear design and engineering calculations. In addition it provided vital experience in the coreloading procedure which will be carried out when the fuel elements are delivered to the Indian Point site later this year. Once installed, the core is expected to operate for about two years without refuelling.



(*Left*) **Exhibits at the Rassegna Internazionale Elettronica Nucleare E Teleradiocinematografica held in Rome recently**

(*Far left*) **Prominent visitors to the Rome exhibition.** (*Left to right*) **Captain G. Bartes, secretary-general of the International Society of Men in Space, Dr. Prof. Hermann Oberth, "father of astronautics," Professor Ambrosine, president of the Men in Space Society and president of the United Nations Commission on Space Law and Dr. Prof. Otto Joklik, vice-president of CIREN, who recently lectured the Institution in London**

NUCLEAR NOTES

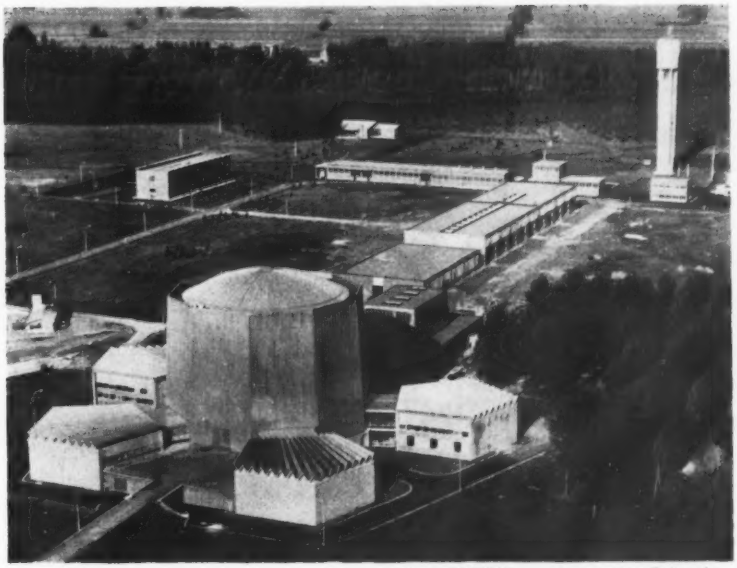
Three million pellets of thorium-uranium oxides, each ½ in. × ¾ in., make up the core's fuel charge. Weighing approximately 40 tons, the assembled core of fuel elements stands 8 ft high and measures more than 6 ft across. It comprises 120 fuel elements and 21 control rods. For the test, the core was installed in a 17 ft high tank 9 ft in diameter. More than 10,000 gal of de-ionized, or purified, water was pumped into the tank before the core was brought to criticality. The station will be capable of producing 275,000 kW of power. Part of its total output will result from routing the steam generated by the reactor system through a conventional oil-fired super heat cycle before it reaches the turbogenerators.

NIMROD subsidence

MINUTE changes of level in the reinforced concrete floor of the giant proton synchrotron now being completed at the Rutherford high energy laboratory of the National Institute for Research in Nuclear Science, Harwell, were periodically registered by a "Talyvel" measuring instrument made by Taylor, Taylor and Hobson division of Rank Precision Industries, Ltd. The measurements in seconds of arc (one second of arc = 5 millionths of an in./in. or 0·005 mm/m) have been taken over a period of a year on a specially sited concrete pad in a subterranean chamber beneath the proton synchrotron. The "Talyvel" is an electronic level indicator consisting of a pendulum co-operating with transducers which provide an electrical displacement signal. This signal is amplified to feed a centre-zero meter graduated in angle and gradient. With suitable mechanical adaption, the instrument can be used to measure verticality or angles.

Belgian coil

THE Desy (Deutsches Elektronen Synchrotron) of the German Government nuclear centre has ordered a nuclear coil weighing 160 tons, for the Hamburg electron synchrotron from Ateliers de Constructions Electriques de Charleroi, Belgium. It is a special coil having an output equivalent to 175,800 single-phase kVAR. It consists of 12 "main" windings (secondary) each of 17,700v and 12 primary windings each of 4,300v. The main windings are given a 50 c/s resonance by means of capacitor banks and connected in series with the coils of the electro-magnets (whose natural frequency is also 50 c/s by other capacitor banks, placed however in parallel with the former). Owing to this special arrangement the potential differences between the windings and between earth and windings are reduced. It is to be noted that the main windings carry a direct current of 680 amp upon which is superimposed an alternating current of 50 c/s, 340 amp peak. The coil will be of the "Air-core" type (with exterior magnetic circuit).



The SORIN reactor at the Saluggia Research Centre, Vercelli, Northern Italy. This reactor has recently been raised to a new rating of 2 MW from its former rating of 1 MW. The final projected maximum output is 5 MW

Australian power station

THREE British nuclear energy experts have recently been discussing with the Australian Minister for National Development the possibility of building a commercial nuclear power station in Australia. The type of station in mind would take 3½ years to build and would have an output capacity of 500 MW.

Control section

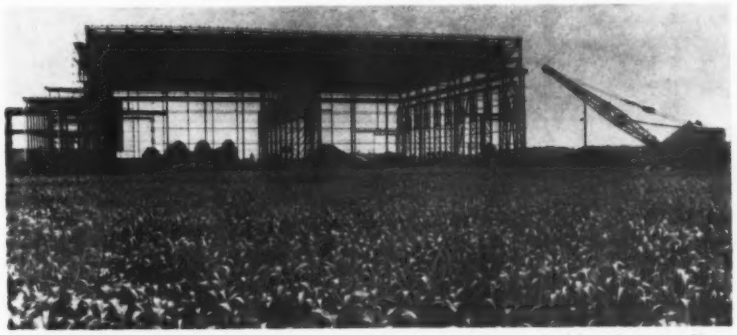
THE laboratory of the Government Chemist has set up a radio-chemical section to provide the Ministry of Housing and Local Government with the information it needs for the control of radioactive substances. Work has begun on the examination of public drinking water supplied from certain areas defined by the Ministry and attention is also being paid to the analysis of effluents from atomic energy establishments.

New colour film

THE European Organization for Nuclear Research has recently produced a 25 min colour film, "Matter in Question," showing the organization's activities. The first sequences of the film recall the history of the study of atomic and nuclear structure, showing some of the contemporary personalities in the world of physics. The organization's equipment and its utilization are shown in detail particularly the big proton accelerators.

Correction

THE caption to the photograph in the bottom left-hand corner of page 235 of our June issue, taken at the Institution meeting on May 9, should have read: Admiral Given (*right*) talking to Captain Grindle.△△△



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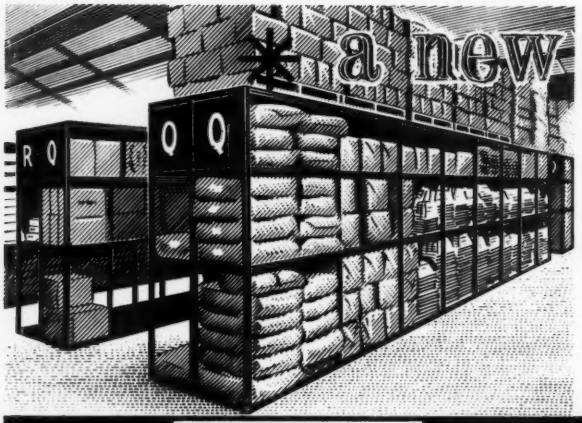

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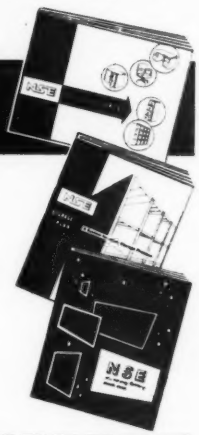

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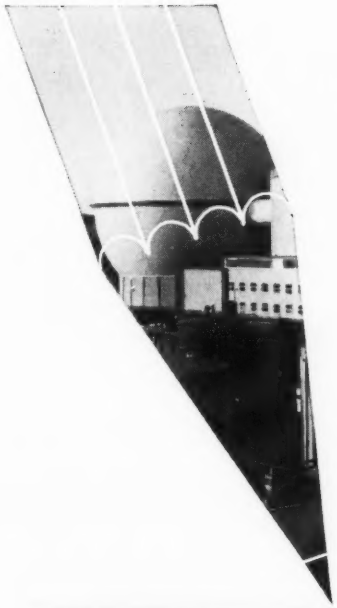

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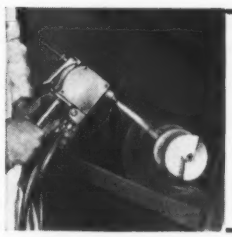

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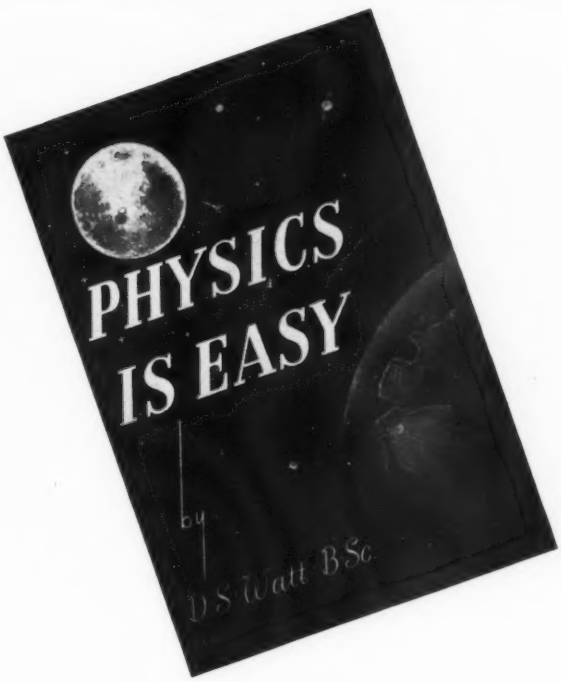

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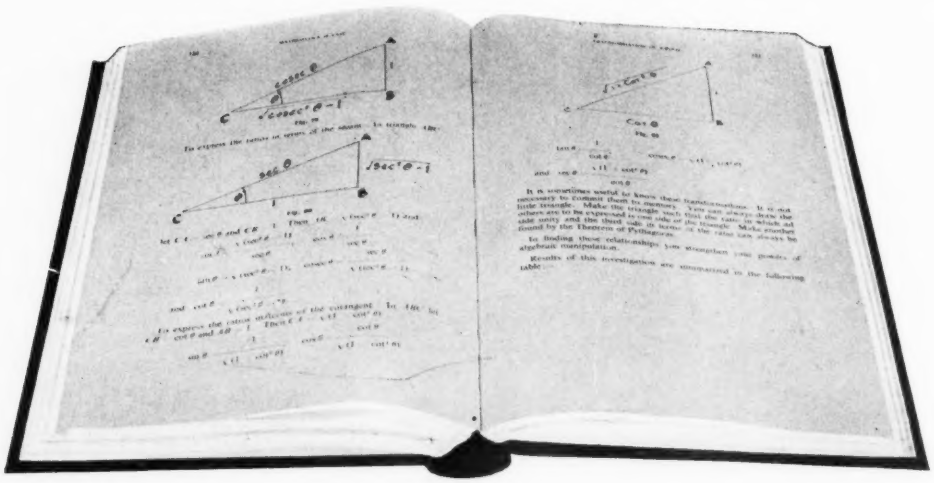

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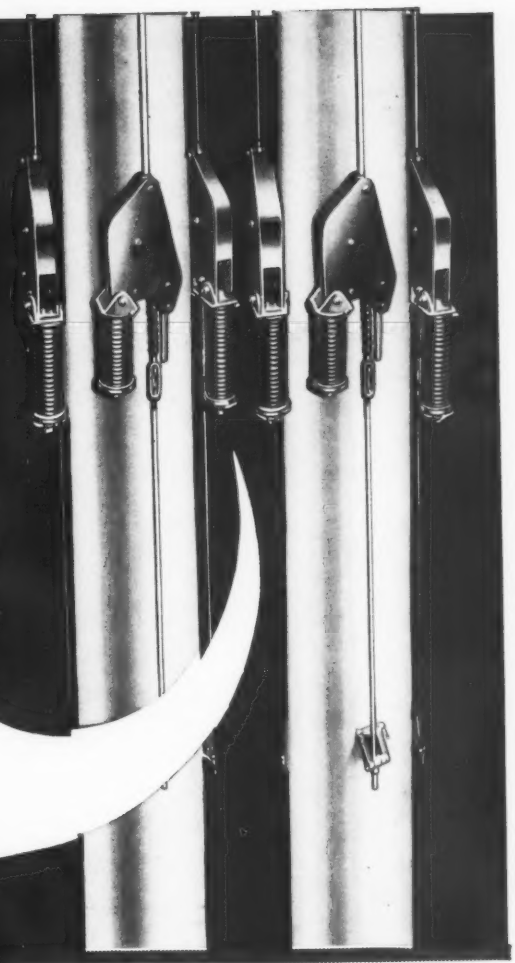

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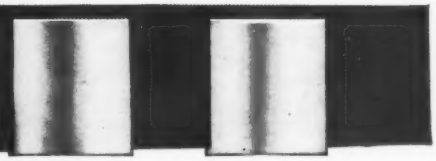

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